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A PROCEDURE TO ANALYZE AND EVALUATE ALTERNATIVE SPACE PROGRAM PLANS

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ABSTRACT

This document summarizes the description of a space program simulation procedure, including required inputs and desirable outputs. The simulation procedure is tailored to evaluate a space program on a national basis. Individual program alternatives can consider exterior influences of other participants in the space program, which could be other government agencies or other countries. The "Program Analysis and Evaluation Procedure (PAEP)" can be best summarized by outlining its major functional steps:

1. Select project-time relationships.

2. Select desired emphasis for each project in terms of number of mission attempts and/or duration of project.

3. Describe and assign space vehicles and destination payloads to be used in each project.

4. Combine chosen projects into different space program plan alternatives.

5. Cost all elements of each project and add or prorate cost burdens.

6. Calculate project yield.

7. Calculate selected yield/cost ratios.

8. Correlate project yields with desired national space program objectives, and determine to what degree these objectives probably would be reached, and thus calculate total program worth.

9. Divide total program worth by total program cost, and thus obtain a measure of program effectiveness.

10. Compare relative program effectiveness of selected program alternatives, and optimize by iteration to obtain maximum return on investment within overall resources available, and thus develop a "most desirable national space program" that can be used as a "baseline" for further repetitive analysis and refinement.

author

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FUTURE PROJECTS OFFICE
RESEARCH AND DEVELOPMENT OPERATIONS

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NOMENCLATURE

Objectives	Space program objectives expressed by individual benefits to be expected from national or international viewpoints.
Weighted Objectives	A priority list of all program objectives is obtained by group judgment resulting in weighted objectives, which are given in percent weight of the sum of the overall objective.
Program	A combination of individual space flight projects established to attain broad national or international objectives.
Sub-Program	Several activity areas are combined in sub-programs (e.g., Earth-planetary operations).
Activity Area	A group of related space projects (such as manned planetary reconnaissance projects) within a sub-program (such as Earth-planetary operations).
Project	A space flight undertaking with a particular goal, consisting of one or more mission attempts to attain the established goal.
Sub-Project	A major subdivision of a project, constituting a group of intimately related missions directed towards a common functional or operational goal within the project; <u>or</u> a particular mode of accomplishing this function or operation based on a peculiar grouping of related major hardware.
Mission	A clearly definable activity comprising one or more flights or operations of an identical nature. Missions may differ according to hardware makeup, customer, or purpose.
Mission Attempt	One or more flight mission attempts have to be scheduled within the constraints of a project to complete the specified mission.

NOMENCLATURE (Cont'd)

Mission Mode	A method of mission implementation, such as lunar orbit rendezvous; it can be described as a specific flight profile on an event-by-event basis.
Flight Attempt	An individual flight attempt with a specific vehicle, based on an assumptional constellation of hardware, purpose, and customer; it is the minimum breakout or description; one or more identical flights yield a mission attempt, one or more mission attempts constitute a mission.
Program Yield	The total produced measurable output of a program in terms of transportation indices, cost effectiveness factors, and milestones reached as a function of time.
Measurements of Yield	Individual yardsticks, which are quantitized measures of accomplishments related to performance, mass, man-roundtrips, time, information rates, etc.
Program Total Cost	Sum of all individual project total costs.
Project Total Cost	All direct and indirect costs associated with a particular project.
Program Worth	An indication of the degree a program is expected to achieve the specified objectives. It is calculated as the sum of the partial worth related to individual objectives specified.
Program Effectiveness	The ratio of program cost over program worth, which indicates the return on the investment for the total program.
Project Effectiveness	The ratio of project cost over project worth, which indicates the return on the investment for the individual project. This is calculated as a differential cost and worth between two programs, one containing and the other eliminating the project under consideration.

ABBREVIATIONS

AFB	Annual Federal Budget
AO	Administrative Operations
C of F	Construction of Facilities
CAM	Cost Analysis Model
CC	Cost Chart
CER	Cost Estimating Relationship
COMSAT	Communications Satellite Corporation
CP	Cost Parameter
DOC	Direct Operating Cost
EC	Effectiveness Chart
EP	Effectiveness Parameter
GNP	Gross National Product
LESA	Lunar Exploration Systems for Apollo
LLV	Lunar Logistics Vehicle
LOS	Lunar Orbiter Survey
LOSS	Lunar Orbital Survey System
MAM	Mission Analysis Model
MOLAB	Mobile Laboratory
MSF	Manned Space Flight
NOA	New Obligation Authority

ABBREVIATIONS (Cont'd)

NSF	National Science Foundation
PAEP	Program Analysis and Evaluation Procedure
PSIT	Program Structure Identification Tables
RASR	Resource Availability Sub-Routine
SSA	Space Science and Applications
TOC	Total Operating Cost
WAM	Worth Analysis Model
WB	Weather Bureau
WER	Worth Estimating Relationship
YAM	Yield Analysis Model
YC	Yield Chart
YP	Yield Parameter

TECHNICAL MEMORANDUM X-53212

A PROCEDURE TO ANALYZE AND EVALUATE ALTERNATIVE SPACE PROGRAM PLANS

SUMMARY

The "Program Analysis and Evaluation Procedure" is the formalization of a methodology to serve as a management tool for program integration. It is a device through which alternative space program plans, while observing the constraints selected by the manager or analyst, can be simulated, evaluated, and analyzed in an integrated fashion. The procedure will permit the study of a great number of alternative courses of action within the basic structure of a national space program, particularly the effectiveness of individual launch vehicles or spacecraft, as well as the relative worth of adding, changing, or deleting an individual space project within any particular space program formulation. The procedure permits the study, in a gross manner, of adjustments within the basic program structure in situations where either the program objectives or available resources are of a changing nature. In the evaluation of the relative worth of one space program alternative versus another, there are many different influences and interplays which must be reflected. Such a procedure is desirable because in order to analyze individual projects within a given space program, it is necessary to study them against the background of a total space program, because of these interrelationships which exist in the form of a capital allocation, commonality of hardware usage and technology, schedule interrelationships, and cost improvement influences. The procedure, therefore, is structured such that questions that are of vital interest to management and decision makers can test the most attractive alternatives in the light of a "real world environment." The procedure will not provide the answers to all of management's questions, but it will assist in the systematic processing of data, which makes it easier for management to choose between available alternative courses of action. The procedure will not make decisions nor does it replace the judgment of the manager.

The purpose of this report is to describe the "Program Analysis and Evaluation Procedure" in detail. This is done for each of the models involved in the procedure by describing the flow of logic and information from the input, through the assumptions, through the calculation procedures, and through the outputs which are made to other models. This report does not state in detail the assumptions that were used in each of the models and it does not give any of

the results which could be obtained from such a model. Each model in the procedure is discussed from the viewpoint, not only of what it contributes, but how it relates to the models from which it must receive inputs and to which it must make outputs. Through this discussion, it can be seen that this is indeed a procedure and not a closed form solution which would be represented by one large model. It is instead a group of models, operated in series. The macrologic of the program analysis and evaluation procedure consists of four models, which are operated in series after receiving guidelines from an externally supplied program structure identification procedure. The inputs from this procedure are transformed by the "Mission Analysis Model" into hardware specifications with respect to number and time. The "Yield Analysis Model" then determines the measurable yields of the program. A "Cost Analysis Model" calculates and summarizes all elements of cost and distributes over the users and projects as a function of time. The "Worth Analysis Model" then correlates the yield of the program with the objectives and measures the degree that those objectives are expected to be accomplished within a given alternative space program formulation, relative to another alternative formulation. The total worth thus derived is then correlated with the cost of the program and a program effectiveness (cost divided by worth) factor is derived, which is then used to compare various program alternatives.

The "Program Structure Identification Tables" provide the program administrator with several input options at various levels of depth. Thus management furnishes guidelines to develop alternative space program plan at five levels of complexity. The guidelines at which these levels exist concern five major items: (1) A statement of the program objectives; (2) expected available resources; (3) the program structure guidelines; (4) the project guidelines; (5) space vehicle guidelines. All of these guidelines, except the program objective guidelines are used as inputs to the Mission Analysis Model. The program objectives guidelines are used as inputs to the Worth Analysis Model.

Using inputs from the Program Structure Identification Tables, the Mission Analysis Model calculates and/or establishes the requirements for each mission and project within a specified program. The requirements are set forth by the Mission Analysis Model in terms of mission mode description, physical description of all mission hardware, and detailed schedules of all design, development, test, and launch operations. These data are then output to the Yield Analysis Model and the Cost Analysis Model.

The Yield Analysis Model attempts to measure the potential merit of all elements of the program alternatives in a consistent and systematic manner, and, thereby, provide a basis for judgment and comparisons. Specific measures of accomplishment, or yield parameters are selected to allow expression of the expected return from each mission and project and to allow quantitative measures to be compiled for each program alternative under examination. All yield measures within this model are determined and quoted on an expected value basis, using estimates of launch vehicles and spacecraft reliabilities. The yield parameter outputs from this model are inputs to the Worth Analysis Model.

The Cost Analysis Model determines the cost and funding requirements for the design, development, testing, operations, and facilities of the hardware for the projects which are output from the Mission Analysis Model and the yield analysis model. These costs are actually generated in four major categories: design and development, facilities, operational and institutional support. From these computed costs, total program costs and funding can be determined and used to calculate the various effectiveness measures of the space program. Thus the outputs of the Cost Analysis Model are used as inputs for the calculation of certain measures of effectiveness within the Yield Analysis Model and the Worth Analysis Model.

The purpose of the Worth Analysis Model is to correlate the program yield which is an output of the Yield Analysis Model with the program objectives which is an input furnished by the Program Structure Identification Tables. The Worth Analysis Model is a formalized procedure for relating appropriate yields with the program objectives and deriving functions to represent this relationship. The output of the Worth Analysis Model must always to viewed as relative to the output of one alternative space program versus another. It in no way reflects absolute value judgments. When the program worth is combined with the program total costs, a measure of program effectiveness is available, establishing a common basis for program alternative program comparison.

Many thousands of bits of data can be derived as outputs from the Program Analysis and Evaluation Procedure. To be effectively used, these outputs must be organized and integrated into a logical coherent pattern. A total of five output options are offered to management at the following information levels: (1) National program totals; (2) agency program totals; (3) total program trends versus time; (4) subprogram totals; and (5) subprogram trends. There are three categories of information within each of these five output levels: (1) Program cost; (2) program yield; and (3) program effectiveness. In addition to these basic output options many detailed outputs from exercising the program analysis and evaluation procedure can be obtained for detailed study of any particular area.

CHAPTER I. INTRODUCTION

The purpose of this document is to describe a procedure that is under development at the George C. Marshall Space Flight Center (Future Projects Office) for the purpose of evaluation of alternative program plans within the structure of the national space program. An analytical procedure has been developed for initial testing as a management tool for evaluating entire space programs as well as individual projects within a given program plan. This tool, designated "Program Analysis and Evaluation Procedure (PAEP)," can be used to analyze several alternative program plans with a reasonable level of effort. This calculation procedure consists of several individual models to facilitate easy handling and to provide flexibility. The detailed inputs and outputs for the models are defined and illustrated and some discussion of the calculation procedures to be followed is given.

PAEP was developed to provide the capability to respond quickly to requirements concerning the evaluation of alternative plans for the future national space program. Thus the goal of this effort is the development of a true program synthesis procedure, which should have the ability to: (1) construct a sample program including all types of activity that might be of interest in the time period considered; (2) select a cost-optimum mix of vehicles and systems to accomplish the sample program, including the ability to recognize that, if a given vehicle system is not required, its development costs need not be paid; (3) use a Worth Analysis Model to determine the relative worth of the sample program; (4) perturb the sample program in all areas and determine the change in worth for each perturbation, thereby performing an iteration process to derive the best possible program within given resources and other constraints. Such a synthesis procedure need not necessarily be completely computerized. In fact, with the present degree of understanding of the overall problem, complete computerization would be extremely undesirable since it would probably limit flexibility and further inhibit understanding of the overall problem.

The following discussions relate some ideas on the evolution of the initial version of PAEP, as described in this document, into a fully integrated, partially automated simulation procedure. The discussions are concerned with general guidelines and aims, model system conceptual design, and model system design philosophy.

Some <u>general guidelines and aims</u> are listed below:

1. A real time simulation of large space programs for time periods of up to 30 years is desired.

2. Real money values as anticipated in this time period shall be used, but constant dollar values should be an option.

3. Simple input and output formats with variable options for computer time and accuracy shall be available.

4. The computation models shall be programmed initially for the IBM 7094 computer. A future review of the program status with regard to core memory size required, computational speed, and flexibility of operation shall determine the suitability of the IBM 7094 versus other machines for ultimate employment with the system.

5. The Fortran IV language shall be used initially for programming. A future review of the program status with regard to program size, ease of modification, anticipated growth, and estimated usage shall determine the suitability of Fortran IV versus alternative coding languages for ultimate employment with the system.

6. The individual models of the system shall be structured to provide growth potential, either towards greater detail in factors already simulated, or towards the inclusion of more factors to be simulated, or both; this growth is to proceed without basic re-structuring of the models.

7. The individual models shall be designed in such a way that continuous updating of governing parameters, constants, and relationships within any model shall be effected with a minimum of effort.

8. The program simulation procedure, once established, shall be exercised on a periodical basis, constantly refining each of the elements and strenthening each of the conclusions by including newer data, as it becomes available, and more expert decision judgments, as these are developed. In this manner, the "program prediction curve" will be continually better fitted, and with increasing confidence, to a statistically increasing sampling of "data points."

9. Thought shall be given to possible issuance of a periodic (quarterly) long-range prognostication document, based on best estimates of future activities, drawn from the continuous system operation described in item 8 above.

Having defined the chief goals of the program simulation procedure, the conceptual design philosophy of the procedure will be discussed. The actual information flow path is specified by assigning each calculation to one of several models. Thus, the aggregate of all the models forms the program simulation procedure. Each model represents a "natural, individual phase" within the total system.

The design philosophy of the program simulation procedure is based upon the following considerations and goals:

1. The procedure must be flexible enough to simulate any conceivable sequence of operations that can be said to define a program.

2. Formats, units, and conventions shall be standard from one model to another, and throughout the program simulation procedure.

3. Each model shall be complete within itself. If need be, it will be operable independently of any other model, using inputs that are all manually supplied, rather than accepting inputs from a previously operated model. Each model may be developed and modified independently.

4. Models will avoid duplication of calculations performed by other models.

5. No model need necessarily be represented by a single deck of cards, although this may prove to be desirable in some cases.

6. Results from each model must be capable of being reviewed in a coarse sense, to filter out groups of inferior or undesirable cases, before transmitting data on to the subsequent model. For this purpose, each model will.be assigned its own constraints, by which "filtering" judgments may be performed. These decisions, by their nature, are not meant to precisely select certain valid alternatives, but rather to reject totally invalid alternatives, for which a continuation of the evaluation would clearly be unwarranted.

7. The overall simulation procedure should also be capable of being operated in a course sense by specifying only a minimum of input data for rapid, preliminary study or, alternately, it should be capable of being operated in a fine sense, by defining and specifying the various operations in sufficient detail to include all high-order effects desired.

8. The procedure should be capable of running through complete ranges of values, in either regular or irregular sequences, of any or all parameters that pertain to a given project.

9. The models should be readily modifiable by a programmer having only moderate experience, without the need for extensive training on these particular model systems.

10. The procedure must be easy to update, so that current advances in technology, theory, methods of approach, and knowledge of the various governing physical parameters can be incorporated with a minimum of effort.

11. The procedure should be operable at as many computer installations throughout the country as possible.

12. Data must be easily input by a non-specialist engineer or management analyst. At each level of input fineness, there should be a mechanism to guarantee that exactly the proper number of inputs have been specified, each in its proper format, and all inputs in the correct sequence.

13. Emphasis must be on clearness and readability of the output, again by the non-specialist or unfamiliar operator. A choice of several levels of output complexity must be provided, ranging from a brief summary of major performance specifications to a detailed breakdown of subsystem requirements, i.e., the degree of detail can be specified at anytime during the input operation.

14. Types of output capabilities include paper plotter tape; card punch tape, for input to other models; and paper print-outs of three types:

a. Synoptic, i.e., a complete, real-time-sequence narrative of events in fluent style describing the projects with outputs inserted in the proper places.

b. Summary, i.e., a summary of all desired outputs in abbreviated tabular format.

c. Detailed outputs.

After identifying the "ideal simulation procedure," which is probably not achievable, attempts will be made to approach this goal as near as possible. However, first preference will be given to a practical procedure, which permits an early application. In this way, a gradual buildup of the simulation procedure becomes possible, and valuable experience is gained, as the system is tested and evolved into an acceptable management tool.

The following persons made significant contributions in the areas indicated during development of the simulation procedure, and their effort is greatly appreciated by the editors:

1. H. O. Ruppe and J. D. Hilchey - Program Structure Identification Tables (Chapter VI).

2. J. W. Carter, H. G. Hamby, and V. Gradecak - Mission Analysis Model (Chapter IV).

3. L. T. Spears, D. Paul, L. H. Ball, and J. N. Smith - Yield Analysis Model (Chapter V).

4. T. H. Sharpe and C. H. Rutland - Cost Analysis Model (Chapter VI).

5. W. G. Huber, G. R. Woodcock, C. H. Rutland, T. H. Sharpe, H. O. Ruppe, and V. Gradecak - Worth Analysis Model (Chapter VII).

In addition to those listed above, the following persons rendered valuable assistance during the numerical evaluation of the pilot exercise and the preparation of this report: R. J. Davies, G. T. Detko, R. Festa, R. L. Moak, S. H. Morgan, W. R. Payne, S. Ross, J. J. Smith, and E. E. Waggoner.

CHAPTER II. MACRO-LOGIC OF PROGRAM SIMULATION PROCEDURE

The macro-logic of the "Program Analysis and Evaluation Procedure (PAEP)," shown in Figure II-1, is composed of the following models and calculation routines:

1. Program Structure Identification Tables,

2. Mission Analysis Model,

3. Yield Analysis Model,

4. Cost Analysis Model,

5. Worth Analysis Model,

6. Program Characteristics (Outputs).

The "Program Structure Identification Tables (PSIT)" summarize all pertinent guidelines and directives received from top management. Five input options are offered with increasing depth proceeding from level one to level five and are described in Chapter III.

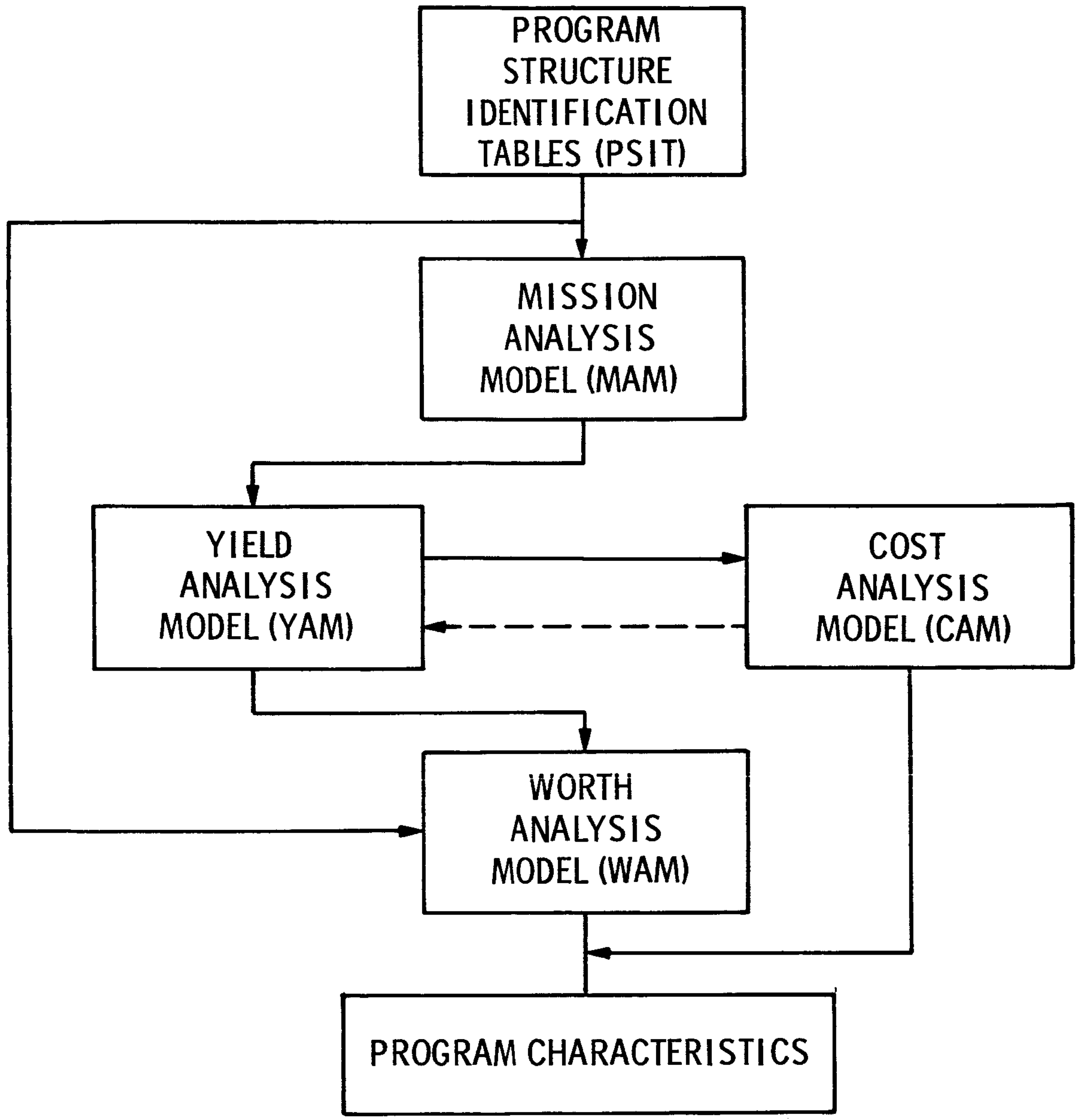

FIGURE II-1. MACRO-LOGIC OF PROGRAM ANALYSIS AND EVALUATION PROCEDURE (PAEP)

These program guidelines cover the following major topics:

1. Program Objectives,

2. Available Resources,

3. Program Structure Guidelines,

4. Project Guidelines,

5. Space Vehicle Guidelines.

These tables, which are prepared in the form of checklists, give top management the opportunity to express their preferences in a concise manner, and instruct the group of analysts, in an unmistakable way, regarding the program alternatives that they want evaluated. These guidelines also establish the time and resources frame of reference considered to be realistic at that time.

The analyst will then, to the best of his ability, complete these input tables where top management elected not to state a preference. The detailed inputs required are described in Chapter III.

These guidelines provide the essential inputs for the other models of the calculation procedure described in this report.

The "Mission Analysis Model (MAM)" will produce the following information:

1. A <u>master flight plan</u> compiling all mission attempts for the selected space flight projects under consideration.

2. A <u>mission mode data bank</u> containing all required information concerning customer, destination, crew size, launch windows, velocity requirements, etc., for each maneuver and flight times for each phase of the mission.

3. A <u>flight hardware data bank</u> containing all major hardware elements required to accomplish the selected missions via the preferred mission modes. This includes dry-weights, propellant weights, major dimensions, performance and availability data for each propulsion stage, spacecraft modules, and destination payloads considered.

4. A <u>hardware schedule</u> summarizing the number of units required as a function of time to satisfy the master flight plan.

The required data is compiled from various available mission studies and previous pilot exercises of this simulation procedure as well as from NASA Project Offices in case available flight hardware is involved. The MAM is described in detail in Chapter IV. The output data of the MAM serves primarily as an input to the "Yield Analysis Model."

The "Yield Analysis Model (YAM)" will estimate the expected performance of all space transportation systems for each mission destination in terms of mass and people delivered. The YAM will also indicate at what point in time the desired missions might be accomplished considering the number of mission attempts scheduled and the expected reliability of the used flight hardware.

The program evaluation procedure requires three types of yield parameters:

1. "Quantity" type parameters (mass or people delivered),

2. Cost-effectiveness type parameters,

3. Time parameters (program milestones reached).

The yield parameters used at this stage as a measurement for the return on the investment (program worth) have been selected with the goal in mind that programs for a time period from 1970 through 1990 (and later) are the subject of the investigation. A total of 44 yield parameters have been identified as possible indices for measuring the expected performance of a space program alternative. It is the purpose of the YAM to offer well defined procedures that will result in numerical values for all of these parameters chosen for the worth analysis of a program alternative. In addition to determining the program yield, the YAM will determine the number and rate at which reusable space flight hardware should be manufactured. This is done by considering the master flight plan operational life, turn-around time, initial reliability, and reliability growth expected for each piece of hardware. A final manufacturing schedule is arrived at in this way, which is the basis for the "Cost Analysis Model." The YAM is described in further detail in Chapter V.

Using the outputs from the YAM, plus necessary external cost inputs, the "Cost Analysis Model (CAM)" calculates the cost and funding requirements for all flight hardware; operations; facilities; and design, development, testing, and engineering for each project. The CAM is described in Chapter VI.

One of the possible constraints for the CAM is the anticipated limit of available resources that could be imposed by the "Program Structure Identification" inputs by top management. In this case, the resources availability subroutine calculates a projection of the resources that would possibly.be available for use by each customer to (NASA, DOD, Weather Bureau, COMSAT, etc.) carry out its share of the program. These projections of resource availability are then compared to the resource requirements output from the CAM. If there are significant differences, either more or less, between the requirements and availability, adjustments will be made through the MAM and iterated until the difference becomes small.

Aside from calculating expected R&D and operational cost, the CAM has "Cost Estimating Relationships (CER's)" for facilities and for institutional burdens. The model will further distribute the total cost as required over the time span considered and allocate the proper cost shares to each of the projects, sub-programs, and customers. As one of its primary tasks, this model is doing a large amount of bookkeeping to make sure that the proper cost does end up in the right cost accounts.

The "Worth Analysis Model (WAM)" estimates the expected return on the investment on the basis of the specified (weighted) objectives established by top management, using the expected program yield. For this purpose a "Worth Estimating Relationship (WER)" has been derived for each of the stated objectives. The independent variables of these WER's are selected yield indices that are considered most representative and are used as yardsticks for the performance of the program. The number of terms selected for each equation is proportional to the weight assigned to that particular objective. The numerical values for each of the yield parameters are obtained with the help of the YAM and CAM. The WAM is described in detail in Chapter VII.

Finally, all of the relevant data required for decision making is presented in the form of tables and graphs, as described in Chapter VIII. The following five levels of detail are offered as an output option:

1. National Program Totals,
2. NASA Program Totals,
3. National Program Trends,
4. Sub-Program Totals,
5. Sub-Program Trends.

Within these five output levels, there are three categories of information:

1. Program Cost,

2. Program Yield,

3. Program Effectiveness.

The last category is primarily the ratio of suitable cost and yield parameters. A total of 95 different parameters have been selected for presentation and are considered to satisfactorily describe the characteristics of a typical program. They are grouped in approximately 160 to 190 charts, depending on the number of program alternatives analyzed.

This simulation procedure can be used to answer a large number of questions concerning the "best" structure of an extended space program. In general, the Program Analysis and Evaluation Procedure can be iterated until management feels that the particular program plan under examination satisfies the basic objectives used to formulate the plan, and represents the most desirable alternative.

The procedure described here was developed to permit creative interrogation of a model representing the best possible extrapolation of the "real world environment." In this fashion, it becomes a tool for gaining insight into the problem and can assist the decision maker in sharpening his judgment and arriving at well founded decisions in a relatively short time.

CHAPTER III. PROGRAM STRUCTURE IDENTIFICATION TABLES (PSIT)

A. GENERAL DESCRIPTION

The "Program Structure Identification Tables (PSIT)" provide the Program Administrator with several input options at various levels of depth. In cases where management does not exercise the most detailed input option, the team of analysts assigned to the evaluation task will complete these major input data sheets to the best of their ability.

The format of the input tables was chosen so that a minimum of time is required by the Administrator to fill out these tables. Where possible, they are arranged in the form of checklists and/or questionnaires indicating the choices available.

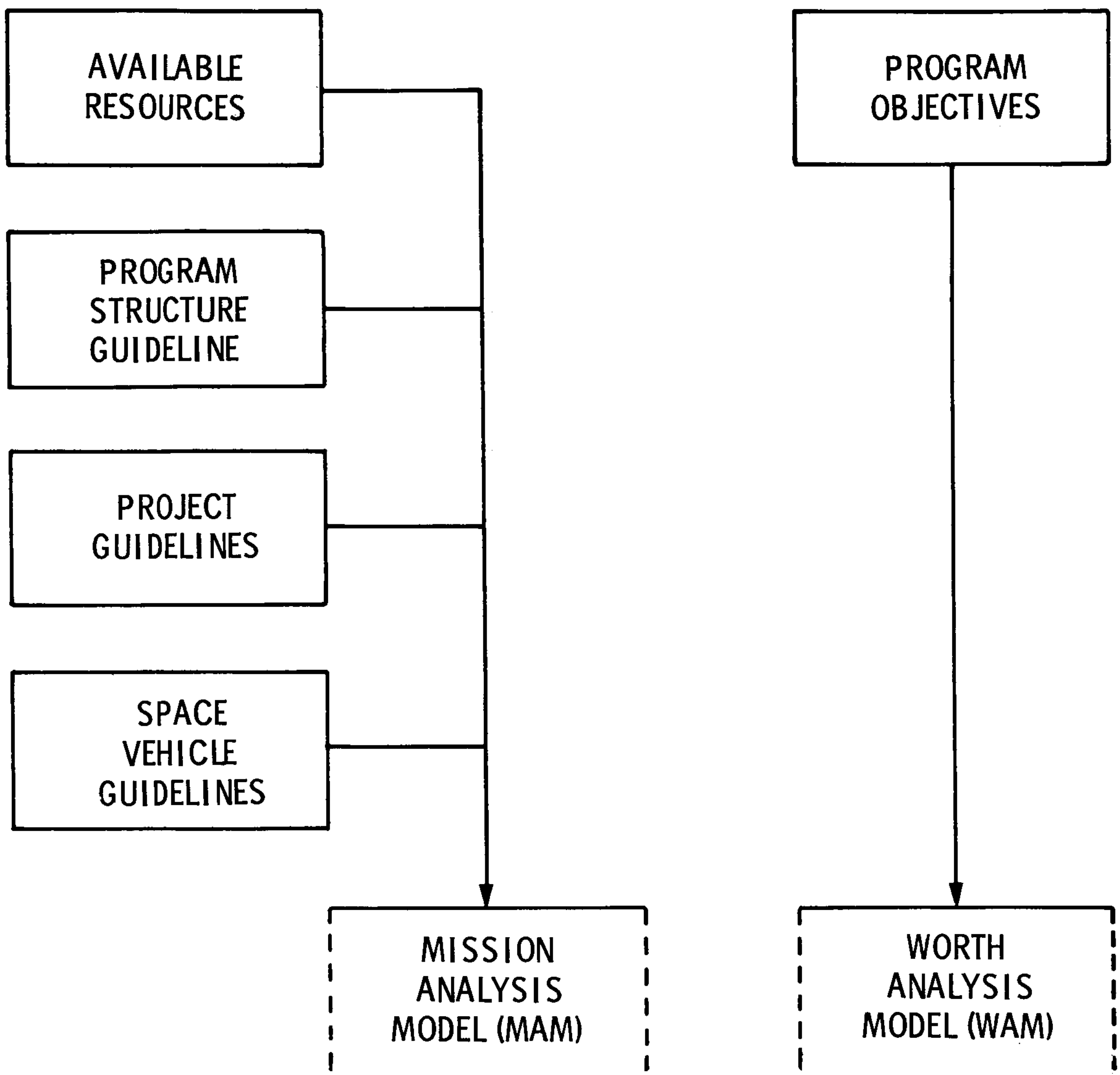

FIGURE III-1. PROGRAM STRUCTURE IDENTIFICATION TABLES (PSIT)

Figure III-1 shows the elements of the PSIT's. First the overall "program objectives" have to be stated in order to have a yardstick against which the relative worth of each program alternative can be measured.

Next, the level of budgetary resources expected to be available has to be given to set an expenditure pattern around which one can attempt to optimize each program alternative. Normally, more than one level of budgetary resources will be selected by the Program Administrator and thus will lead to other program plan alternatives.

The "program structure guidelines" give the Program Administrator the opportunity to assign the resources expected to be available to the sub-programs of his choice, thus indicating sub-program priorities.

The "project guidelines" offer management the opportunity to single out all those projects within each sub-program to be included or excluded. The Program Administrator can also indicate his desires on priority and set a target date. This is done by checking complete project lists, which list all potentially attractive (and identified) space projects by title or by short description.

Finally, with the "space vehicle guidelines," the Program Administrator has the option to indicate his preference concerning the use of available or potentially available space vehicles and transportation systems. These are again listed in the form of a checklist in the same manner as the project guidelines. The input options available to management are summarized in Figure III-2. A detailed description of all these input tables follows.

LEVEL	PROGRAM OBJECTIVES	EXPECTED AVAILABLE RESOURCES	PROGRAM STRUCTURE GUIDE-LINE	PROJECT GUIDE-LINES	SPACE VEHICLE GUIDE-LINES
1	√	—	—	—	—
2	√	√	—	—	—
3	√	√	√	—	—
4	√	√	√	√	—
5	√	√	√	√	√

FIGURE III-2. INPUT OPTIONS

B. PROGRAM OBJECTIVES

Without a statement of the objectives of the space program, it is very difficult to compare alternative program plans on a common basis. For this reason a "weighted objective list" was derived, which can be used as a yardstick for comparison if no other common base is specified by the Program Administrator.

This list of program objectives is based on the objectives laid down by Congress in the National Aeronautics and Space Act of 1958. This act contains eight major objectives. The list prepared here is an expansion of these major points which have been subdivided, where appropriate, and defined in such a way that they are more suitable for measurement purposes. Following the definition of these 20 objectives, a poll was taken within the senior people of an experienced space flight development team, considered to be representative, on the relative importance of these partial objectives. The answers of 60 "judges" provided a statistical basis for assigning weights to these objectives in percent of the total program objectives. The resulting weighted objective list is given in Table III-1 and can be used as a standard if no other distribution is preferred by the Program Administrator.

It is important here to note that neither too few nor too many objectives should be contained in such a weighted objective list, because in the former case, the weighting procedure becomes too sensitive, and not sensitive enough in the latter case. At this point in the testing phase of this evaluation procedure, it is felt that no less than 10 and no more than 20 objectives should be included in such a list.

As a first test of this weighted objective list, a correlation was attempted with the major benefit areas of space flight, namely:

1. Political benefits,

2. Economical benefits (including general welfare),

3. Military benefits,

4. Scientific benefits,

TABLE III-1. LIST OF WEIGHTED OBJECTIVES OF THE NATIONAL SPACE PROGRAM

PRIORITY	PARTIAL PROGRAM OBJECTIVES	WEIGHT IN PERCENT STANDARD DISTRIBUTION	WEIGHT IN PERCENT ADMINISTRATOR'S CHOICE
1	Achieve and preserve U. S. international leadership (by demonstration of actual space flight capabilities and scientific accomplishments).	8.2	
2	Utilize new knowledge and technologies, obtained from space flight activities, for the benefit of mankind (such as weather forecasting, communications, navigation, medical applications, materials, productivity techniques, etc.).	8.0	
3	Space activities will provide more insight into, and understanding of, the fundamental physical nature of the universe and of life itself.	6.1	
4	Develop a technological and industrial base, which can support national security needs for manned space systems with relatively short leadtime.	6.1	
5	Raise the level of general knowledge in many areas of human activities, and provide the incentive for improved education.	5.9	
6	Promote international cooperation for peaceful purposes (thus reduce world tension and strengthen the cause of peace).	5.8	
7	Stimulate the nation as a whole, by engaging in large-scale space flight development and operations (thus providing a sense of purpose and excitement for the nation, as well as creative opportunities).	5.7	
8	Stimulate the national economy, by providing incentives for new investments, to raise employment.	5.6	
9	Demonstrate operational feasibility and utility of space systems, which may be applied to national security requirements.	5.5	
10	Space activities will result in a major expansion of knowledge about the terrestrial and space environment, which is required for the development of aeronautical and space transportation systems.	5.3	
11	Strengthen the educational facilities and build direct relationships for scientific experiments and training of scientists and engineers.	5.2	
12	Maintain and expand industrial base continuity, including contracting and management practices (thus enabling the U. S. to cope with complex problems and systems when required).	4.9	
13	Space activities will result in the availability of dependable and efficient manned space transportation systems for a wide range of potential applications.	4.8	
14	Strengthen, within the government, the capability to manage the development of complex systems, and find solutions to complex problems (thus strengthening and preparing the government for times of crisis).	4.3	
15	Provide the capability of overt inspection to enforce arms control agreements, while providing an alternate channel for resources utilization during the adjustment period of the national economy.	4.0	
16	Space vehicle development will result in a capability to transport personnel and cargo very rapidly to any point on this globe.	4.0	
17	Development of new policies, procedures and systems to make most effective use of scarce special skills, capabilities, and other resources (thus enhancing the competitive position of the U. S. in the area of foreign trade).	3.0	
18	Space vehicle development and operation will greatly improve aeronautical transportation systems.	2.8	
19	Space activities will result in the availability of dependable and efficient unmanned space transportation systems.	2.6	
20	Exploit extraterrestrial resources for the benefit of mankind.	2.2	
	TOTAL	100.0	

5. Technological benefits (primarily in the form of transportation systems). Each of the 20 weighted objectives was assigned to the benefit area where it was felt the individual objective would contribute most. This resulted in the information shown in Table III-2, and indicates a strong lead by the economical benefits, followed by political benefits, and the other three areas with approximately equal weight. At first glance this correlation appears plausible, but will require further refinement as experience with this method is gained by practical application.

TABLE III-2. CORRELATION OF PROGRAM OBJECTIVES WITH MAJOR BENEFITS

	PROGRAM OBJECTIVES	POLITICAL BENEFITS	ECONOMICAL BENEFITS	MILITARY BENEFITS	SCIENTIFIC BENEFITS	TECHNILOGICAL BENEFITS
1.	Demonstration of U. S. Leadership	8.2				
2.	Commercial Space Applications		8.0			
3.	Knowledge about Universe and Life				6.1	
4.	Strengthen Military Industrial Base			6.1		
5.	Incentive for Improved Education		5.9			
6.	Strengthen International Cooperation	5.8				
7.	Stimulus of Pride and Performance		5.7			
8.	Stimulus for Investment and Employment		5.6			
9.	Demonstration of Military Applications			5.5		
10.	Knowledge about Earth Atmosphere				5.3	
11.	Strengthen Educational Facilities				5.2	
12.	Strengthen Industrial Capabilities		4.9			
13.	Manned Transportation Systems					4.8
14.	Strengthen Gov't Competence in Technology	4.3				
15.	Means for Arms Control			4.0		
16.	Rapid Global Transport Capability					4.0
17.	Stimulation of Foreign Trade		3.0			
18.	Improvement of Aeronautical Systems					2.8
19.	Unmanned Space Transportation Systems					2.6
20.	Exploitation of Extraterrestial Resources		2.2			
	Total (100)	18.3	35.3	15.6	16.6	14.2

C. AVAILABLE RESOURCES

No Program Administrator knows for sure what resources might be available over an extended period of time. Moreover, the resources available will depend on the competition for these resources and how much "return on the investment" the space program has to offer as compared to the other candidate programs. In such a situation, it is common practice to choose a lower and upper limit for resource availability expected, and try to determine what kind of a program these would offer. This approach is also recommended for this situation. Table III-3 lists five "rules of thumb," which should produce five

TABLE III-3. AVAILABLE RESOURCES INPUT OPTIONS

1	CEILING OF CONSTANT DOLLARS WITH LAST FY NOA AS A BASEPOINT	
2	CEILING OF CONSTANT SHARE OF FEDERAL SPENDING ON THE BASIS OF A BALANCED BUDGET WITH LAST FY NOA AS A BASEPOINT	
3	CEILING OF CONSTANT SHARE OF GNP WITH LAST FY NOA AS A BASEPOINT	
4	CEILING OF CONSTANT SHARE OF GNP FOR DOD PLUS SPACE WITH DOD NON-SPACE BUDGET DECREASING AT RATE OF $ 1 X 10^9 A YEAR (LAST FY NOA AS BASEPOINT)	
5	AS 4 ABOVE, BUT DOD NON-SPACE BUDGET DECREASING AT $2 X 10^9 A YEAR	
A	AGENCY CIVIL SERVICE CEILING CONSTANT	
B	AGENCY CIVIL SERVICE CEILING INCREASING AT HALF THE RATE AS BUDGET (IN PERCENT)	
	OTHER: SPECIFY	

CHECK ONE OUT OF 1 THRU 5 PER PLAN ALTERNATIVE
AND A OR B

representative funding levels to choose from. The continuation of present space funding in absolute dollars is considered the lowest level considered, because any program much smaller than this should be evaluated by simpler methods than this. A practical upper limit is represented by Case 5, where it is assumed that the share of the expenditures for space, and non-space defense within the gross national product (GNP) is not changed in the future; but, within this block an amount of 2 billion dollars per year is shifted from non-space defense to space, but not necessarily to civilian space activities. Table III-3 also offers management a place to give guidelines with respect to manpower ceilings for their respective agency.

D. PROGRAM STRUCTURE GUIDELINES

Table III-4 provides the Program Administrator the opportunity to indicate his preference as to which of the subprograms should have priority when selecting projects to satisfy the established program objectives. In case he does not choose to exercise this option, the resources will be distributed by iteration in such a way that the "overall program worth" is maximized. On the other hand, the Program Administrator might want to choose alternative program plans that have a different structure. This table has to be filled out for each program alternative selected.

TABLE III-4. PROGRAM STRUCTURE GUIDELINES

SUB-PROGRAM \ DEGREE OF ACTIVITY		NONE	SMALL	MEDIUM	LARGE
SUB-ORBITAL	SOUNDING ROCKETS				
	GLOBAL TRANSPORT				
EARTH-ORBITAL	UNMANNED				
	MANNED				
LUNAR	UNMANNED				
	MANNED				
PLANETARY	UNMANNED				
	MANNED				

E. PROJECT GUIDELINES

These tables list all major projects of interest for the foreseeable future, including unmanned as well as manned projects. They are arranged in four subprograms, namely:

1. Sub-Orbital Operations,
2. Earth-Orbital Operations,
3. Earth-Lunar Operations,
4. Earth-Planetary Operations.

Within these subprograms, several related projects are combined in so-called "Activity Areas," resulting in a logical overall program structure. Within this frame of reference, there are some 50 to 100 individual projects to choose from.

TABLE III-5. PROJECT GUIDELINES - SUBPROGRAM A

CODE	PROJECT NAME, GOAL, AND SCOPE	PRIORITY			TARGET DATE		
		MUST	DESIR-ABLE	NICE-TO-HAVE	EARLIEST	PRE-FERRED	LATEST
301							
302							
303							
•							
•							
•							

This list of potential space projects is presented in a table of the format shown in Table III-5 and is called "Project Guidelines." This table gives the Program Administrator the opportunity to indicate his desires as to which of the candidate projects should be included in the program alternative plan to be evaluated. He also can assign these projects to a customer (for keeping the accounts straight), he can assign a priority, and he can establish a desired target date for each of the selected projects. An example of an actual space projects list is contained in an appendix to this report, which can be requested from the Future Projects Office, Code R-FP, MSFC.

In case management does not elect to state a preference for individual or a group of projects, the evaluation procedure is structured so that the analyst can search and find the mix of projects that promises the highest return on the investment (worth) based on the resources available.

F. SPACE VEHICLE GUIDELINES

The space vehicle guidelines serve a similar purpose as the project guidelines (Table III-6). They give the Program Administrator an opportunity to

TABLE III-6. SPACE VEHICLE GUIDELINES - CANDIDATE VEHICLES

CODE	VEHICLE TYPE AND CAPABILITY	PRIORITY			TARGET DATE		
		MUST	DESIR-ABLE	NICE-TO-HAVE	EARLIEST	PRE-FERRED	LATEST
101							
102							
103							
•							
•							
•							

express his preference for using or not using certain types of launch vehicles and spacecraft. In general, however, it appears preferable to develop, by an iteration procedure, the best combination of space vehicle use that produces the highest program worth. Thus, the space vehicle guidelines, shown in the form of an input format in Table III-6, is not a "must guideline" but an option available to the Program Administrator.

If there are no strong reasons for identifying a mix of projects and space vehicles from the outset, the input level 3, providing program objectives, program resource limitations, and basic program structure might be the preferred input level of the Program Administrator.

A set of actual input data sheets is given in an appendix to this report, which can be obtained from the Future Projects Office, Code R-FP, MSFC.

CHAPTER IV. MISSION ANALYSIS MODEL (MAM)

A. INTRODUCTION

Using inputs from the "Program Structure Identification Tables," the "Mission Analysis Model (MAM)" calculates and/or establishes the requirements for each mission and project within a specified program. These requirements are set forth by the MAM in terms of mission mode description, physical description of all mission hardware, and detailed schedules of all design, development, test, and launch operations. These data are then input to the "Yield Analysis Model (YAM)" and the "Cost Analysis Model (CAM)" for use in these procedures. The macro-logic of this process (input, calculation, and output) is shown in Figure IV-1.

This chapter discusses the method of approach, the logic and detailed calculation procedure, and the MAM inputs and outputs.

B. METHOD OF APPROACH

In performing the MAM calculations, two basic approaches can be taken. The first of these would be to designate a probability of successful mission accomplishment that is desired for each project, and then determine the actual number of attempts that are required to achieve that stated probability. If this approach were taken, it would fall into the YAM area; the description follows. The second approach, and the one used here, is to establish a reasonable number of attempts for each project based on expected availability of funding and mission reliabilities using heuristic decision rules. The main reason for taking this latter approach is because of the reduced number of iterations required.

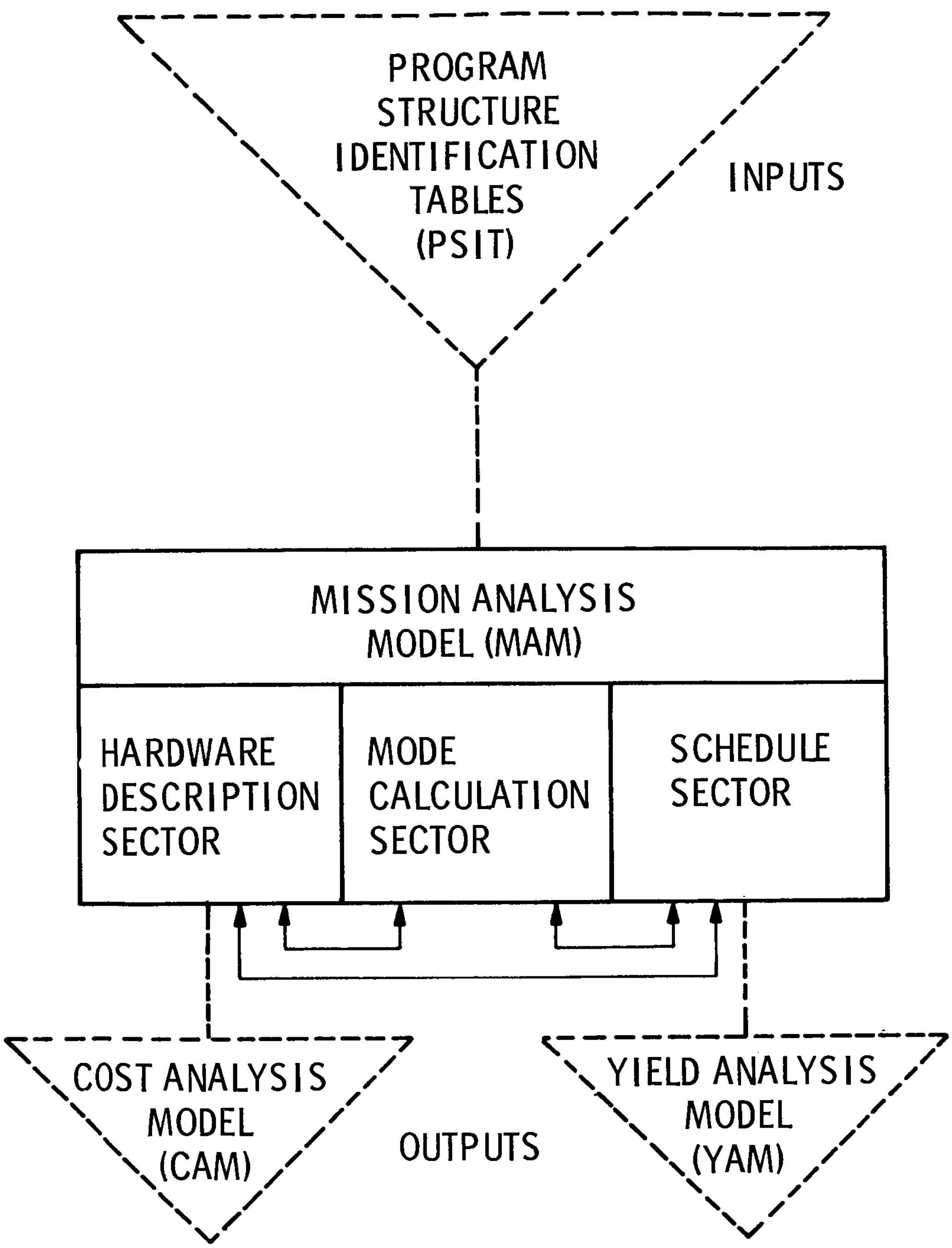

FIGURE IV-1. MISSION ANALYSIS MODEL (MAM) MACRO-STRUCTURE

After the number of flight attempts for a given project are established, the most promising mission mode used in accomplishing the projects must be selected, development schedules required to meet the attempt dates must be derived, and the actual individual hardware used in the various projects must be defined and assigned. It should be realized that this is an iterative process for which separate calculation routines are normally employed to find the "most promising" mission mode. Most alternative program plans of interest involve over 100 different hardware items. Utilization of these individual hardware items must be identified by time period, usually one year, and by the project using it in that particular time period. These hardware uses can be summed by time period, over the projects making up the alternative, to yield the total flight requirements by hardware item per year. This total is used as an input to the CAM. In addition, the hardware descriptive elements are input to the CAM to be used in cost estimating relationships. The YAM receives inputs of detailed launch attempt schedules.

C. DISCUSSION OF LOGIC

In general, the detailed flow diagram of MAM, shown in Figure IV-2, will be discussed here. The logic used in the MAM will be examined from the overall or total program viewpoint before problems peculiar to the subprogram are discussed. The detailed calculation procedure from the subprogram standpoint is discussed in Paragraph E.

Within the MAM, there are three major sectors: mode calculation, hardware description, and schedule. Each of these sectors receive inputs from the Program Structure Identification Tables, which are discussed in Chapter III. The tables are divided into four distinct areas of input, which are of direct concern to the MAM. All of these areas, i.e., project guidelines, available resources option, program structure guidelines, and space vehicle guidelines, furnish inputs to the mode calculation sector. The project guidelines also furnish inputs to the schedule sector, as shown in Figure IV-2. The space vehicles guidelines also provide inputs to the hardware description sector.

Based on the inputs given in the Program Structure Identification Tables, a detailed mission mode is selected from a data reservoir of possible mission modes, and then the payload capability of launch vehicles required to carry out this mission mode is determined. If existing launch vehicles do not have the required capability characteristics for the selected mode, then a vehicle that will meet these requirements will be derived; or, alternatively, a modified mission mode will be selected that can be satisfied by the existing launch vehicle capability. Thus, this sector involves an iterative calculation process.

In actuality, the payloads capabilities and requirements block of the mode calculation sector require inputs from the space vehicle guidelines block; however, this is a secondary input consideration.

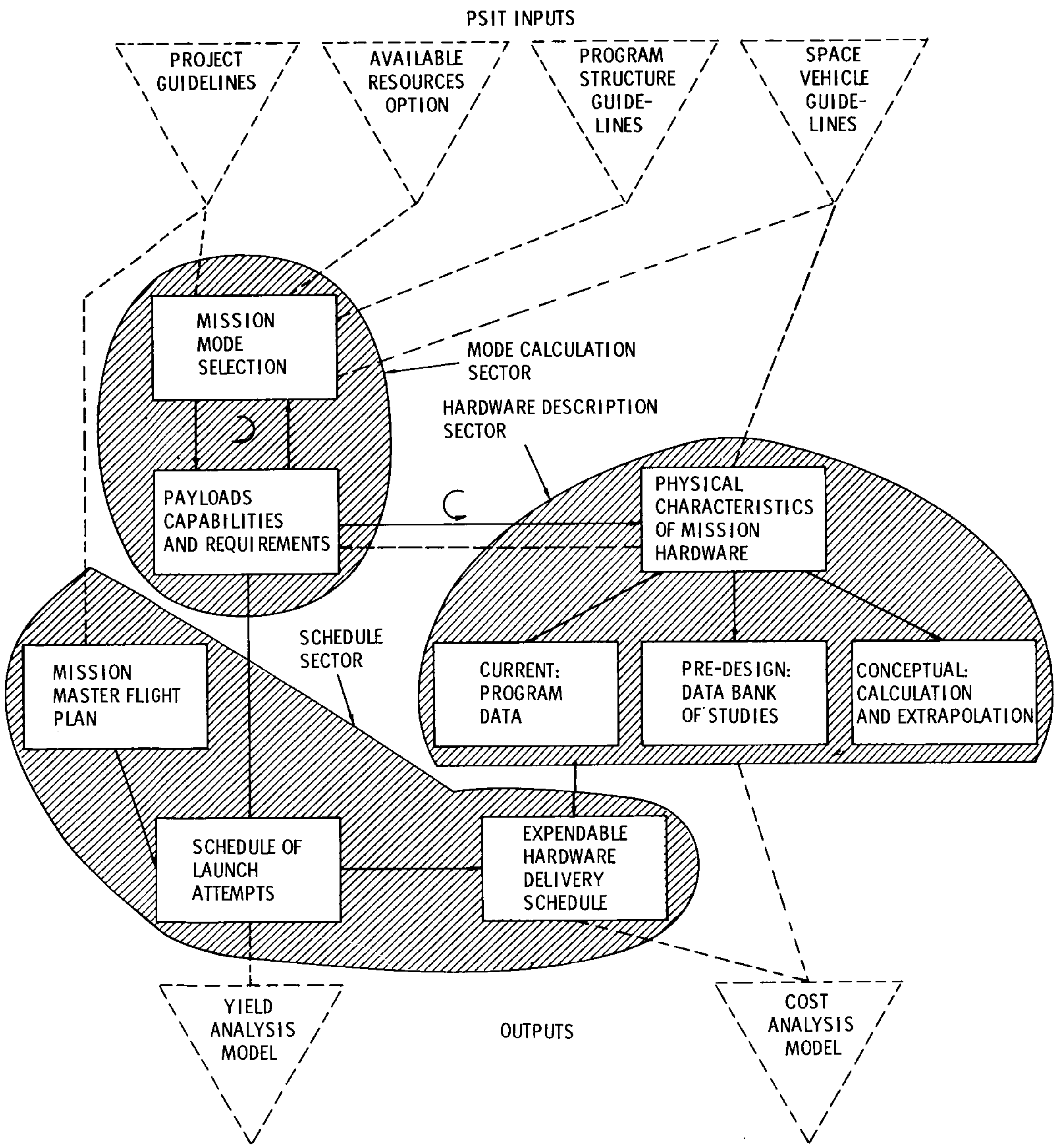

FIGURE IV-2. MISSION ANALYSIS MODEL (MAM) FLOW DIAGRAM

Having identified the major propulsive requirements from the mission mode considerations, the next step is to describe the physical characteristics of these major propulsive elements in terms of weight, volume, dimensions, thrust, specific impulse, etc. Also, those hardware elements that are peculiar to accomplishing the mission itself (destination payload) must also be described in the most appropriate form. This description of the physical characteristics of the mission hardware can be obtained from the hardware data bank. For more advanced hardware, several preliminary design studies have been performed, which provide an extensive data bank. For those hardware items that are more conceptual in nature and for which previous studies have not been performed, a preliminary calculation or extrapolation of physical characteristics must be made on a case-to-case basis.

The schedule sector receives inputs from the project guidelines block, which aids in establishing the mission master flight plan (the actual schedule and number of individual mission attempts within a given project). Subjective judgment, engineering judgment, and programming experience are used in this phase to translate the project guidelines into a schedule of mission attempts. Using inputs from the mission master flight plan block and the mode calculation sector, a detailed schedule of launch attempts is derived for each element of mission hardware involved. This scheduling includes not only the launch events themselves, but also includes all necessary design, development, testing, and construction events that are both hardware and mission oriented. This effort can be defined as only an establishment of a clean bookkeeping system that leaves no doubt as to how many hardware items have to be delivered to each customer in each time period.

With inputs from the hardware description sector, which designates whether the hardware item is reusable or expendable, the schedule of launch attempts can be converted to an expendable hardware delivery schedule. The schedule of launch attempts is output to the YAM, which converts the launch attempts for reusable hardware into hardware delivery requirements. The expendable hardware delivery schedule, as well as outputs from the hardware descriptive sector, are channeled to the CAM.

D. INPUTS AND OUTPUTS

1. Internal Inputs from Program Structure Identification Tables

a. Project guidelines consisting of:

(1) Selecting subprograms,

(2) Establishing priorities,

(3) Setting target dates for mission accomplishment,

(4) Establishing project assignments.

b. Space vehicle guidelines consisting of an indication of preference for:

(1) Space vehicles,

(2) Transportation schemes.

c. Available resources option selects a total resource constraint within which the missions are constructed.

d. Program structure guidelines consisting of:

(1) Establishing broad program objectives,

(2) Estimating optimum program worth,

(3) Choosing alternative program plans,

(4) Pursuing varying program structures.

2. <u>External Inputs</u>

a. List of all attractive modes for mission accomplishment.

b. List of currently available and approved space vehicles.

c. List of advanced space vehicles that could potentially be used for missions.

d. Capabilities of current and advanced space vehicles.

e. Estimates of men and material requirements for each project.

f. Detailed schedule for each project showing necessary design, development, testing, and operations activities.

g. Judgment of launch attempts required for each project.

h. Description of destination payload functions.

i. Estimates of mission lifetime.

3. <u>Outputs to Yield Analysis and Cost Analysis Models</u>

a. Summary chart of each program alternative.

b. Quantities of:

(1) Launch vehicles,

(2) Spacecraft,

(3) Destination payloads.

c. Schedule of launch attempts for:

(1) Launch vehicles,

(2) Spacecraft,

(3) Destination payloads.

d. Description of mission mode selected and detailed mission characteristics.

e. Detailed description of hardware:

(1) Launch vehicles,

(2) Spacecraft,

(3) Destination payloads.

E. DETAILED CALCULATION PROCEDURE

The discussion of the detailed calculation procedure follows along the same line as shown in the detailed flow diagram of Figure IV-2. However, for the sake of clarity and for purposes of illustrating the different types of problems encountered in describing the three major sectors of Figure IV-2, the discussion is divided into the major subprogram areas of orbital, lunar, and planetary missions and projects. Suborbital missions have not been treated extensively and therefore are not discussed here as a separate category; however, the procedure followed in the other subprogram areas would apply to these missions.

1. Orbital Systems

The Earth orbital activity area includes manned and unmanned satellites. The unmanned satellites include communications, meteorological, and a wide variety of scientific applications. The manned operations include development of logistic spacecraft, space station operations at low altitudes and synchronous orbits, and the launching of vehicles from Earth orbit for planetary and lunar destinations.

The area of greatest orbital activity involves space stations because of their logistics supply demand and general utility. Space stations, as envisioned today, are expected to play a major role in research activities, in some military missions, and in support of the general welfare of all nations.

TABLE IV-1. SUPPLEMENTAL MISSION DATA SHEET - ORBITAL

Alternative F		Mission Objective	Mode of Operation	Nominal Manning Level	Nominal Rotational Frequency	Nominal Personnel Breakout	% Time		Logistics Requirements	
Activity Area	Proj. No.						House-Keeping	Produc-tive	Personal #/M/day	Scient. & Eng. Test Total or #/M/Trip
f	50A 50B 50C	Polar Sta. Logistics - PMS Logistics - PMS	Orb. Sta. 12-33/35a/35b Pers. & Log. 8-47/48 Pers. & Log. 13 direct	3/1st yr.; 6 thereafter 2 men/flight 10 men/flight	8 wk/1st yr.; 6 wk/3rd; 4 wk/4th yr.; then 2 wk.	1st yr. Pilot; Co-pilot/Eng.; M. D./Biol., then as above plus 3 eng.; Sci., & Observ.	45	55	10-20	250#/M initial equipment; up to 50#/M/rot.
	51A 50B	Mil. 30° Station Log. 30° Sta.	Orb. Sta. 11-45 Pers. & Log. 13 direct	12/1st yr.; 48/4th, and after 10 men/flight	17 da/1st yr., decrease to 1 wk. in 5th yr.	1st yr. Pil.; Copil.; 2 Eng.; 2 Opn's Crew & 6 Eng., Sci. & Obser. Incr. to 12 crew & 36 transients	45 decr. to 30	55 incr. to 70	10-20	100,000# initial; up to 50#/M/rot.
	52A 52B 52C 52D 52G	Multipurp. Synchr. Sta. SCN to Orbit & Sat V Tank SCN Log. to Sta. Personnel to Orb. Post Sat. Tank. Flt.	Sta. & Log. 12-33/35a/35b; 12-35a/b 11 - 19; 11 - 21 Pers. & Log. 19 (3 stops) Pers. & Log. -13 14 - 22	12/1st yr.; incr. to 36 by 5th yr. 6 men/flight 18 men/flight 10 men/trip	90 days 60 days	1st yr. 2 Stations Pilot; Copilot/Eng; M. D./Biol. & 3 Eng., Sci. & Obs. Min.: 3 Sta. 1 Pil.; Copil.; 2 Eng., 2 Opn's Crew & 6 Eng., Sci., & Observers	Min. 45	Max. 55 100	10-20 10	700-1500# initial 110-120#/M/rot. 20#/M/rot.
	53A 53C	Multipurp. 30^0 R & D Sta. Log. M/P R&D Sta.	Orb. Sta. 11 - 45 Pers. & Log. 13 direct	12/1st yr.; 21/3 rd; 48 there-after 10 men/flight	1 mo/1st yr.; 2 wk/2nd yr. & after	Pilot, Copilot, 2 Eng., 2 Opn's Crew & 6 Eng., Sci., & Observ.; incr. to 42 transients	Decr. to 20	Incr. to 80	up to 20	100,000# initial; up to SO#/M/rot.
	54A	Internat. Sci. Sta.	Orb. Sta. 11 - 45	12/1st yr.; 48/2nd yr. & after		Pilot, Copilot, 2 Eng.; 2 Opn's Crew; 6-42 transient Sci., Eng., & Observ.	Decr. to 20	Incr. to 80		10,000# initial

The Program Structure Identification Tables developed only broad guidelines, established priorities and target dates; they do not provide the details of each mission. The MAM is used for development of all essential details. Since space stations are the backbone of any orbital subprogram, it appears desirable to describe a representative example to reflect the approach used for detailed development of each mission. Table IV-1 is a typical orbital mission data sheet. In general, the following events are typical of how each orbital mission is developed:

a. Compare the target dates to predicted technology state of the art to determine the feasibility of each mission and to identify problem areas that have to be solved.

b. Evaluate the demand for volume onboard the station to determine the overall size and the station's function.

c. Identify, as a function of demand, the experiments and other activities so that subsystems performance can be developed.

d. Identify, as a function of the onboard activities, the skills required to carry out the jobs and to determine the total number of personnel required.

e. Select, from available concepts, or create a preliminary design based upon the onboard activities, crew size, and launch vehicle payload capability. This is used to determine the development period, create data for the CAM, and to confirm the target dates.

f. Based upon the demand, the number of stations can then be determined along with the orbital altitude and inclination, rotation rates, logistics requirements, and the complete flight schedule. As each station's lifetime expires, it is replaced with a new one. As reusable launch vehicles become available, they are immediately employed.

g. The mode of operation is usually dictated by the launch vehicle payload capability and the mission objectives. For instance, it may be reasonable to assume that all polar stations are launched manned and the crew is returned when the mission is completed, because these missions are mostly military in nature. The manned synchronous satellites are initially supplied by Saturn V flights, followed later by a nuclear ferry vehicle taking care of the traffic between a low orbit altitude and the synchronous altitude. The large research laboratories are launched unmanned on a Saturn V and later staffed by Saturn IB's and Reusable Orbital Transports.

h. When the schedule is finally established, the mode of operation specified, and the hardware described, appropriate inputs are made to the Cost and Yield Analysis Models.

2. Lunar Systems Operations

The MAM has the primary objective of taking the selected inputs of the Program Structure Identification Tables (PSIT) and optimizing and detailing such parameters as the specific mode of operation, describing the hardware items and requirements, and compiling a listing of the number of launch attempts necessary to accomplish the program objectives.

Elements required to be developed by the MAM would be the velocity requirements for the mission, ranges of specific impulse expected, flight hardware mass fraction, launch vehicle availability, reliability and growth patterns, reusability of certain hardware elements, turn around times, peculiar operational characteristics, and logistics requirements.

The PSIT's, plus the other external constraints listed above, then furnish a set of design guidelines or a descriptive physical model wherein the projects are required to function.

A run through for a particular set of conditions and PSIT inputs will best illustrate the functional interrelationships and the output capabilities of the MAM for the lunar subprogram. The particular case selected is where the lunar subprogram has considerable emphasis and the Earth orbital and planetary areas receive a nominal effort.

Figure IV-3 is a bar graph representation of this example lunar exploration program. The layout of operational duration is a function of the known or anticipated mission requirements and is also an indication of the length of time that each mission or project can provide the necessary utility. This expected utility or project lifetime is, of course, influenced by the growth rate of the basic transportation system.

Since all programs are particularly sensitive to transportation capability, we are assuming that the launch vehicle programs are to be pursued vigorously. Thus, due to a relatively inexpensive transportation capability if compared to the manned planetary subprogram, the lunar subprogram can be expected to achieve intensive activity.

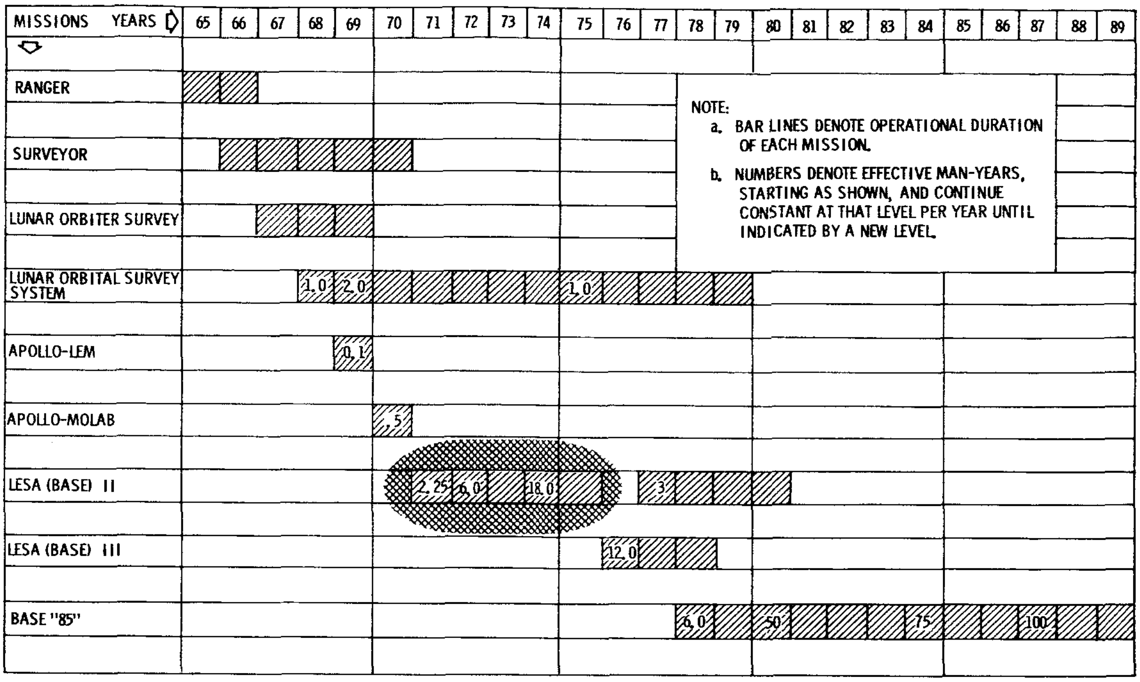

FIGURE IV-3. LUNAR PROGRAM OUTLINE - ALTERNATIVE F

The modes of lunar exploration are not changed significantly for any of the alternatives considered until after the completion of the Apollo program. The Apollo program is extended to encompass a MOLAB concept and then expanded directly to the LESA bases with the development of the LLV. This allows the first significant mode deviation, that of direct flight for the cargo and logistic support requirements. Again the next mode shift occurs only with the development of a new family of transportation vehicles, whereby the Earth orbital-lunar ferry approach becomes more economical, and really large inroads into lunar exploitation can be accomplished.

In the early phases of lunar exploration, the hardware characteristics are fairly well defined by the current program definitions. The first lunar base data are supplied directly from a backlog of studies in this field. The data for large bases are usually obtained by a linear extrapolation of the trends as established by our advanced systems analyses.

The base sizes are in general anticipated in the matrix of conditions obtained from PSIT's for each alternative. Thus, with the exception of the early

Apollo derivative programs, the launches are adjusted to compensate for base size learning curves and reliability growth estimates. The mix of personnel-cargo flights is adjusted so that there is an assurance of logistic balance for a particular base size and mission requirement. Then the launches, cargo and passenger flights are simply counted as a first step to layout of an integrated flight plan. This listing of launch requirements, payloads characteristics, etc., then forms a basis to anticipate ground support criteria, manufacturing needs, training flights, and other pertinent logistic support detail.

An example of the tabulation of a specific mission (LESA Base Model II) is shown in Table IV-2. This tabulation is the result of considering the launch

TABLE IV-2. TYPICAL MISSION REQUIREMENTS TABULATION

MISSION OBJECTIVE	NUMBER AND FREQUENCY OF ATTEMPTS	LAUNCH VEHICLES REQUIREMENTS AND FLIGHTS	SPACECRAFT REQUIREMENTS	REMARKS
BASE II				
Personnel (APOLLO-B)	3/1971; 8/1972-73	(19)-12	(19)-31b, 32b, 34b	3 Men-LEM-LOR
Personnel (APOLLO-Direct)	6/1974-1975	(12)-12	(12)-31b, 41	3 Men-Direct Flight
Personnel (APOLLO 6-Direct)	1/1977-1980	(4)-12	(4)-35, 41	
Logistics	2/1971 4/1972-73 6/1974-75 2/1977-80	(30)-12	(30)-41 (16) -180, 181 (14) 188	LLV Payloads

rate capabilities for each transportation mode as a function of time. The launch rate allocation to a particular operations sector (such as lunar operations) is dependent upon the emphasis that the operation sector is receiving in a particular alternative.

In Column 1 the number and frequency of launch attempts is tabulated for the kinds of payloads. Column 2 sums the number of launch vehicles required for each payload and gives a coding number for each launch vehicle. Column 3 sums the numbers of payloads and gives the coding numbers for these respective payloads.

The compilation of these launch and payload requirements for each mission objective is one of the basic inputs for determining program costs and yields.

The schedule of launch attempts is a measure of material requirements in terms of expendable cargo delivered and outputs into the cost analysis effort. The launch attempts include an estimate of reliability growth as a function of time and number of launches which prejudges the actual reliability analysis which is performed in the Yield Analysis Model.

3. Planetary Systems

For each selected project, a time schedule is established in accordance with the schedules for all supporting projects. As an example, a particular mode selected for a minimum Mars landing mission can be briefly characterized as follows:

> "From a pre-established Earth orbit, transfer a nuclear ferry through a Hohmann ellipse into a Mars orbit. Disengage the nuclear ferry into an orbiting station and a Mars module. Have orbiting station orbiting in its Mars orbit until a later reassembling. Send Mars module down to Mars surface for soft landing on a pre-assigned spot, using air-braking descent. Stay on Mars surface until the mission is completed. Launch Mars module into Mars orbit, to rendezvous with orbiting station. Reassemble Mars module and orbiting station into a nuclear ferry. Transfer this nuclear ferry by a Hohmann ellipse into an Earth orbit."

The project breaks down into single steps, each one carried out by proper methods and vehicles; the steps are consecutive or simultaneous. In the previous example the steps and the energy required (ΔV) are:

a. Transfer by a Hohmann ellipse from Earth orbit to Mars orbit - 5.390 km/sec.

b. Disengage the nuclear ferry into orbiting station and Mars module - very small.

c. Orbiting station in Mars orbit - very small.

d. Descent to Mars surface using air-braking to achieve a soft landing - 0.612 km/sec.

e. Perform the scientific mission on Mars surface - very small.

f. Launch Mars module into Mars orbit - 5.713 km/sec.

g. Rendezvous Mars module and orbiting station into nuclear ferry. (Steps c, d, e, f, and g are simultaneous) - very small.

h. Transfer nuclear ferry by Hohmann ellipse from Mars orbit to Earth orbit - 5.390 km/sec.

Each maneuver requires a certain amount of energy depending strongly on the mode of activity. The total as outlined above is 17.105 (plus reserves) km/sec.

Each single step requires a certain time of performance. In the case of stay-over on a surface, or in an orbit, this time is arbitrary; however, it is limited by practical considerations.

The flight time for Step a. is assumed as 170 days (depending on velocities available, time of departure from Earth orbit, mode of flight, etc.). The corresponding time for Step h. might be 260 days, and the time for Step c. might reasonably vary from 10 days in a 1978 mission to 440 days in a 1990 mission.

Return payload mass is defined as that mass that reaches Earth orbit on the return trip from the mission. For a Mars landing mission, 40 tons of return payload mass for the early flights is assumed.

The crew size is chosen with reference to flight requirements, and scientific objectives at the target planet. For a Mars landing mission, 6 men depart from Earth orbit in 1978, 3 of them going to Mars surface. These figures could increase to 50 men for a 1990 mission. The level of crew comfort can be chosen to be from a minimum through modest, fair, high, to maximum.

For early flights, maximum comfort level is necessary in the fields of shielding, safety, reserves, etc. This requirement will decrease for later flights, while the demands for comfort in living space per man will probably increase with time. The comfort level is determined by several factors, which are:

a. Life support

b. Electric power generation

c. Shelter's protection

d. Tools, equipment, instruments

e. Living space per man

For a Mars landing mission for 1978, the requirement matrix is:

a.	Life support	13 tons
b.	Electric power	6.7 kw (weight 3.3 kg)
c.	Shelter	20 tons
d.	Equipment	2 tons
e.	Living space	1.5 m^3/man

For each vehicle, or for each separate part thereof, a specification and performance sheet is prepared, containing at least the following information:

a. Type

b. Propulsion (I_{sp}, T, T/W_e)

c. Vehicle size (volume, height, diameter, weight, mass fraction)

d. Permissible launch rates (depending on launch facilities, etc.)

e. Reliability (initial, growth)

f. Schedule of development, fabrication, testing

g. Recovery reliability for each separate element

h. Operational lifetime for each element.

i. Refurbishment rate, and schedules

j. Special characteristics

The comfort level, together with the accuracy of the injection and flight parameters, determine the probability of mission success.

The schedule in real time for a Mars landing mission after R&D (1967 - 1977) is completed is: Attempt the first flight in 1978 and subsequently one flight each in 1980 and 1982.

F. SUMMARY OF MAM OUTPUTS

This entire chapter on the MAM has discussed the method by which the essential data are gathered and organized such that the missions and projects making up a total space program can be properly analyzed and evaluated. Therefore, the discussion has centered around how the outputs are derived without really bringing to focus clearly and exactly what they are. The purpose here is to present output data sheets in the form in which the data are prepared to be used as inputs to the YAM and the CAM.

Code	Alternative F	Flight Requirement By Code Type per Yr. (No. of Flight in case of reus. Veh.)-Calendar Yrs																									
	Nomenclature	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	Total
1	SCOUT	14	14	14	14	8	8																				72
2	Th... nted DELTA			5	3	3																					22
				8	1[illegible]																						[illegible]50
	...ITAN III								12	12	12	12															
8	TITAN III-C				4	4	4	4	6	6	8		2	2	6	6											52
9	SATURN I-B (2 Stage of Orbit)	2	5	5		4	6	6																			28
10	SATURN I-B/CENTAUR (3 Stage				2	2	2	5	6	6	3																26
11	SATURN V (2-Stage to Orbit)											1	16	8	5	12	5	2	3	1	4	3		4		1	65
12	SATURN V (3 Stage)			2	4	9	20	9	17	17	24	22	23	25	25	21	19	10	11	11	11	9	10	11	9	10	329
13	REUSABLE ORB. TRANSPORT									20	60	89	117	93	105	129	203	233	268	318	318	318	337	333	333	333	3607
14	Post-SATURN (2-Stage)													2	5	4	7	6	9	7	9	6	11	7	7	7	87
15	Post-SATURN (3-Stage)														3	4	4	4	4	4	6	6	6	8	8	8	65
17	Orbital Launch Vehicle (Mod. S-IVB)															1							2				3
18	Orbital Launch Vehicle (Mod. S-II)													2	2						1						5
19	Orbital Launch Vehicle (PHOEBUS Core) (Taking Half)														2	6	10	6	11	6	8	6	6	8	6	6	81
20	Orbital Launch Vehicle (NUCLEAR PLUSE)																	1	1	1	1		4				8
21	Cryog... Tanker (for SAT. V)												16	6													28
22	Cr... Tanker (for Post-SA...													2	3			5								7	68
23	...ker fo...																										10
																											40

FIGURE IV-4. TYPICAL FLIGHT REQUIREMENTS BY CODE TYPE PER YEAR

TABLE IV-3. LAUNCH VEHICLE DATA SHEET - REUSABLE ORBITAL TRANSPORT

	FIRST STAGE	SECOND STAGE
● TOTAL STAGE WEIGHT AT LIFT-OFF (LB):	1,055,825	267,790
Propellants and fluids (LB):	905,495	220,503
Stage inert weight (LB):	145,660	47,287
Personnel and Misc. (LB):	4,670	24,810
● PROPELLANT TYPES:	LOX-RP	LOX-LH_2
● ENGINES		
No. and type:	1-F1 (uprated) 2-H1 (uprated)	3000 PSI
Thrust per engine (LB):	1800K/200K	380K
● EXPECTED NUMBER OF FLIGHTS PER STAGE (FOR REUSABLE STAGES):	183	162
● EXPECTED REFURBISHMENT COST PER FLIGHT (PERCENTAGE OF STAGE PURCHASE PRICE):	.72%	.72%
● STAGE TURN-AROUND TIME (FOR REUSABLE STAGES)(DAYS):	5.3	5.3
● TOTAL VEHICLE WEIGHT AT LIFT-OFF (LB):	1,348,425	

Figure IV-4 shows typical hardware delivery schedules by year for some of the hardware elements used by the various missions and projects in a total program plan. This schedule is used by the CAM to calculate the effect of cost improvement assumptions.

Table IV-3 summarizes the physical characteristics of the reusable orbital transport as being typical of a new launch vehicle development which could be used with many postulated space programs. This data is used by the CAM to calculate the design, development, and test cost as well as the first unit hardware cost.

ALTERNATIVE A		USER	MISSION OBJECTIVE	NUMBER AND FREQUENCY OF ATTEMPTS
ACTIVITY AREA	PROJ. NO.			
a	01	NASA/SSA	Research Satellites	6/yr 1965-70
	02	"	Scientific Res. High Alti. Orbits	3/yr 1965-70
	03	"	"	3/yr 1965-70; 6/yr '71-'72; 3/yr '73-'74
	04	"	"	6/yr 1975-89
	05	"	"	3/yr 1965-72; 6/yr '73-'74
	06	Foreign Sales	"	12/yr 1976-89
b	07	U. S. Weather Bureau	Weather Satellites	3/yr 1965-74
	08	"	"	3/yr 1975-89
c	09	COMSAT	Com. & Navigation Satellite	1-'65; 1-'66; 2-'67
	10	COMSAT	"	4-'68; 2/yr 1969-75

TABLE IV-4. MAM OUTPUT DATA SHEET - PROJECT SUMMARY

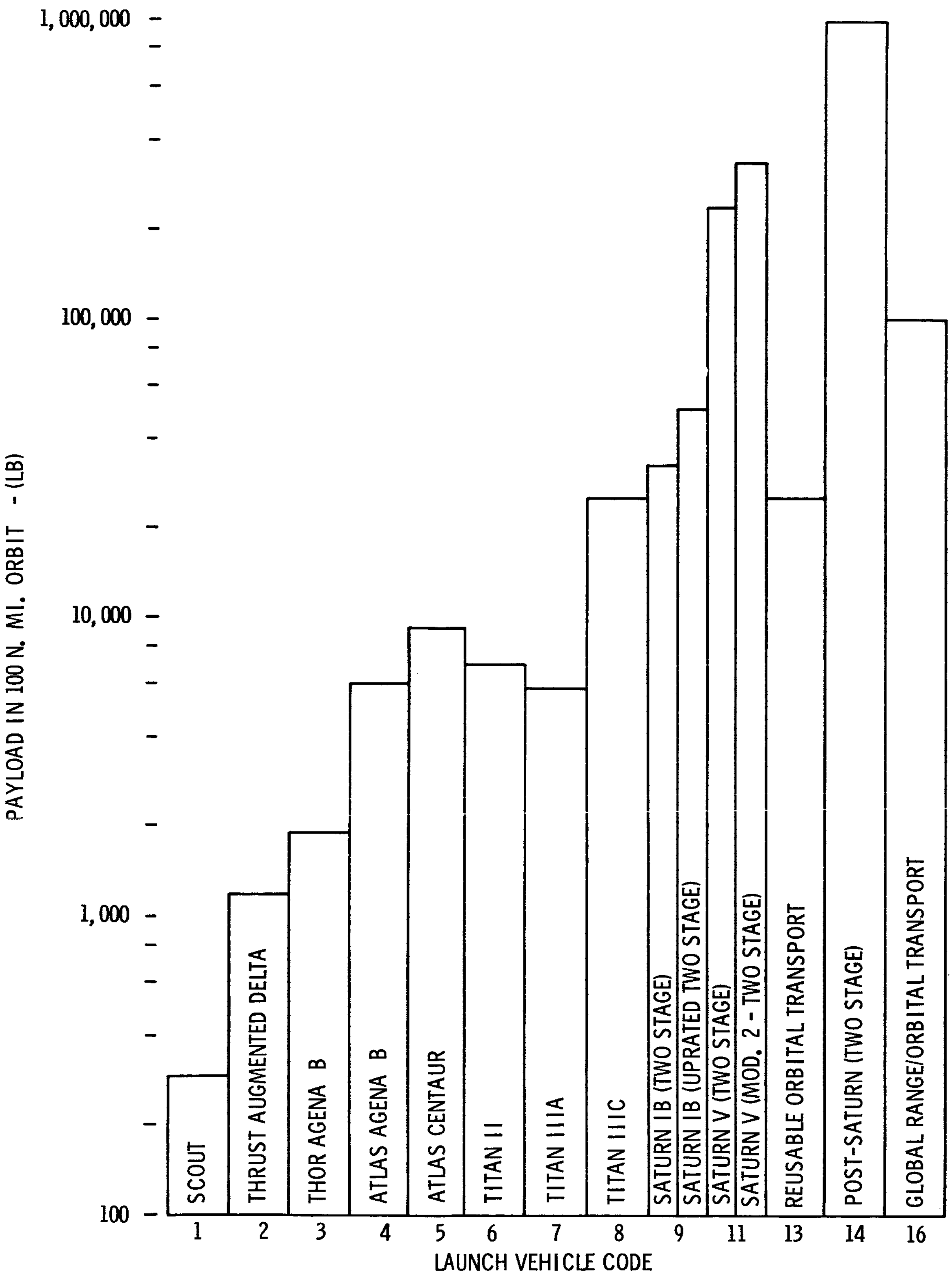

FIGURE IV-5. LAUNCH VEHICLE PAYLOAD CAPABILITY

Figure IV-5 and Table IV-4 are typical of and summarize some of the data output by the mode calculation sector of the MAM. The payload capability of the launch vehicles is shown in Figure IV-5, and Table IV-4 describes the mission mode. The outputs of this sector are used internally by the MAM; however, they are also used to some extent by the YAM.

CHAPTER V. YIELD ANALYSIS MODEL (YAM)

A. INTRODUCTION

The overall objective of the space program simulation procedure is to provide a systematic method to aid in judgment of space program alternatives, in terms of the expected return on the investment.

The "Yield Analysis Model (YAM)" attempts to measure the potential yield of all elements of the program alternatives in a consistent and systematic manner, and thereby provide a basis for judgment and comparisons. Specific measures of accomplishment, or "yield parameters" are selected to allow expression of the "expected return" from each planned mission and project, and to allow quantitative measures to be compiled for each program alternative under examination. The actual evaluation of these yields in terms of relative value or worth is performed within the "Worth Analysis Model," which is discussed in Chapter VII. The yield parameters used in MSFC analyses to date will be listed and discussed later in this chapter. It is likely that the choice of yield parameters will vary to some extent in each exercising of the program simulation, depending upon specific interests at the time.

The yield or accomplishments from a planned project or mission can be discussed either on an "if successful" (100-percent reliability) basis, or on a probabilistic basis. If based on the former, none of the risk elements are reflected in the analyses and results. Where the results are not tempered at all by pitfalls in premature attempts, overly ambitious attempts, and the complexity of mission modes or equipment, the results would definitely be biased toward "high risk" plans. Even when realizing our limitations in predicting probabilities of success and failure in future undertakings, it is felt that yield results on a probabilistic basis will be more meaningful and useful. For the present time, however, in these analyses, all yield measures are determined and quoted on an "expected value" basis, using estimates of launch vehicle and spacecraft reliabilities. Consistency in analysis methods and comparisons cannot eliminate uncertainties in these predictions, but will enhance the validity of the comparisons and results. Sample results from yield analyses will be presented in the concluding paragraphs of this chapter.

B. CALCULATION/COMPILATION PROCEDURES

The relationship of the "Yield Analysis Model (YAM)" within the overall program simulation procedure has been described in Chapter II.* This includes specific interfaces with the "Mission Analysis Model (MAM)," the "Cost Analysis Model (CAM)," and the "Worth Analysis Model (WAM)."

The yield analysis inputs, calculation procedures, major assumptions/estimates, and resulting outputs will be described in more detail in the following paragraphs.

1. Basic Procedure

The yield analyses and compilation consist of two basic parts. One is to establish and compile the nature and quantity of yields for successful missions. The second is to temper these results with estimates of success probability for all necessary elements.

Figure V-1 represents the input and calculation flow process in a gross form. Selected areas of the analysis/compilation are shown later in the form of expanded views of parts of the model.

2. Mission Yield Potential

The first step within the YAM is to determine quantitatively in a consistent manner the mission capability for each project, for the combination of hardware elements, the selected mission modes, and the mission attempt schedule as prescribed from the MAM. It must be determined, for example, the number of passengers and/or the quantity of cargo that can be landed on the Moon in a direct flight mode, with specified space vehicles. Estimates of mission equipment and expendables are then used to determine the maximum number of people and gear that could be delivered and sustained on the lunar surface with the prescribed vehicles and launch rates. This represents the yield potential, or the yields attainable if all elements are completely successful.

a. Orbital Operations

The mission capability calculations are fairly straightforward for missions involving direct flight modes. However, where ambitious manned planetary missions are based on extensive orbital operations, a

*A listing of mission yield parameters selected for use in MSFC analyses to date, and their corresponding definitions, is provided in Paragraph C of this chapter.

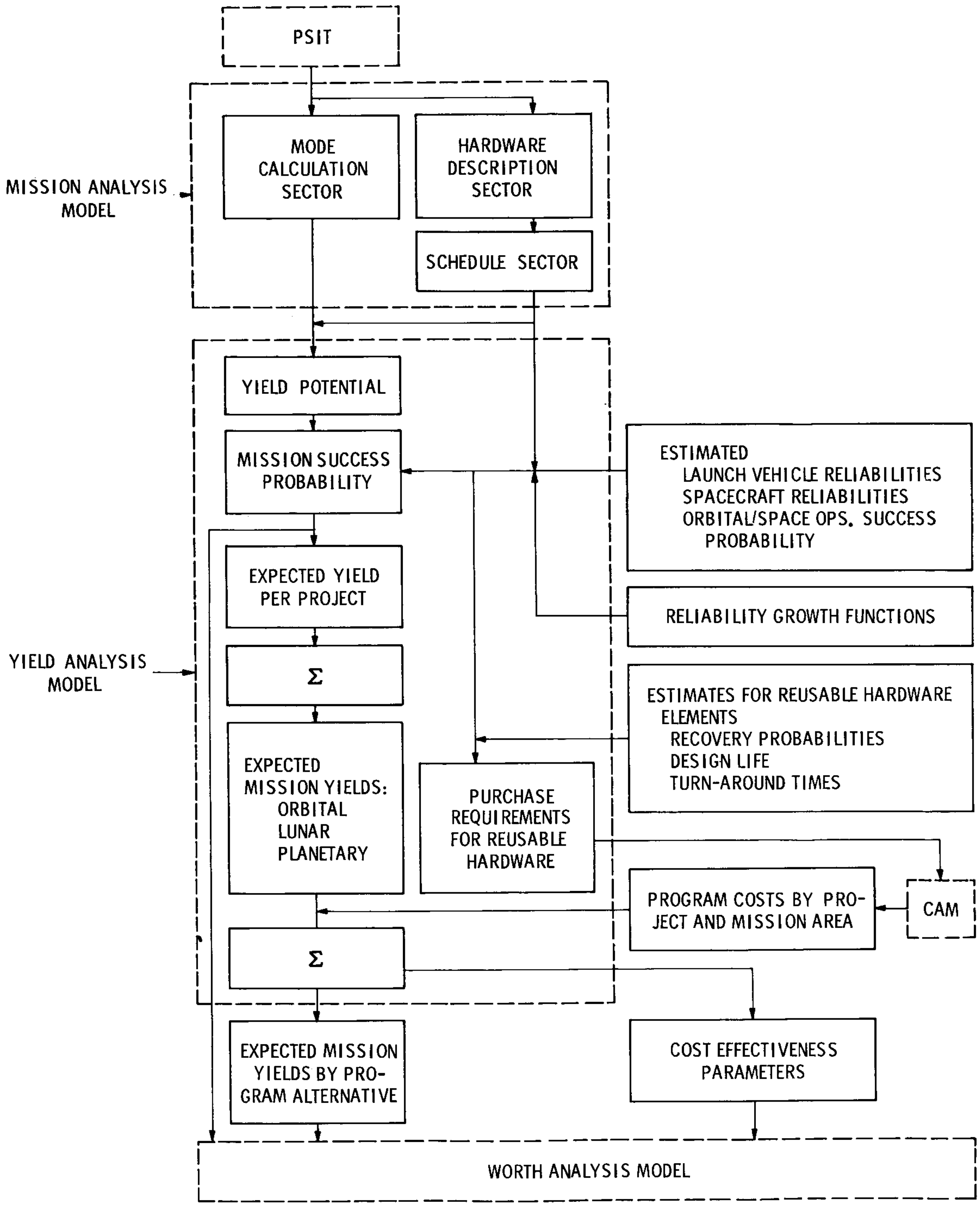

FIGURE V-1. YIELD ANALYSIS MODEL (YAM) MACRO-STRUCTURE significant part of the orbital payload is consumed in the orbital assembly and servicing operations. This consideration can be factored into the analysis in one of two ways. The additional launchings for tankers, for orbital launch facilities, etc., can be included on a judgment basis in establishing the launch schedules. Or alternatively, empirical relationships have been established with which the additional Earth orbit payload and costs (orbital burdens), over and above a given Earth orbit departure mass, can be determined. The latter requires an iteration in the launch schedule establishment.

b. Measurements of Mission Yield

The specific parameters that have been selected as units of measure for the mission yields are listed and defined in Paragraph C of this chapter. These have been grouped into three categories: (1) "quantity" type parameters, such as cumulative Earth orbital payload, man-years on the lunar surface, etc.; (2) "milestone" type measures, such as "year of first manned Venus flyby," etc.; and (3) "cost effectiveness" parameters such as "$ per pound to Earth orbit," "$ per man-year on lunar surface," etc.

3. Mission Success Probabilities

Having decided that failure potential (or conversely, success probabilities) will be considered in attempting to measure the merit of the various alternatives, a choice is necessary between two optional approaches. In one option, a mission objective or yield level can be specified, along with a desired confidence level. The yield analysis would then work backwards to determine the launch rates, equipment, and mission modes necessary to achieve this goal. In the other option, the space vehicles and attempt schedules are established on a judgmental basis, and the yield values are the output of the yield calculations. The latter allows iterations, in effect becoming more nearly like the first option.

In the MSFC analyses to date, the latter method has been used. However, preliminary procedures have been established for use of the former method in subsequent exercises.

a. Equipment Reliabilities

The basic step in establishing success probability estimates is to compile reliability estimates for the items of hardware to be used, and the functions they are to perform. Given these raw data, their combination into success probabilities for each launch and project attempt is fairly straightforward.

The major launch vehicle stages are typical of the major elements for which reliability estimates are required. The procedures used in compiling the launch vehicle reliability projections will be described as an example of this portion of the analyses, and hopefully will convey the attempts made to be as realistic and consistent as possible in these estimates. This procedure is shown graphically in Figure V-2.

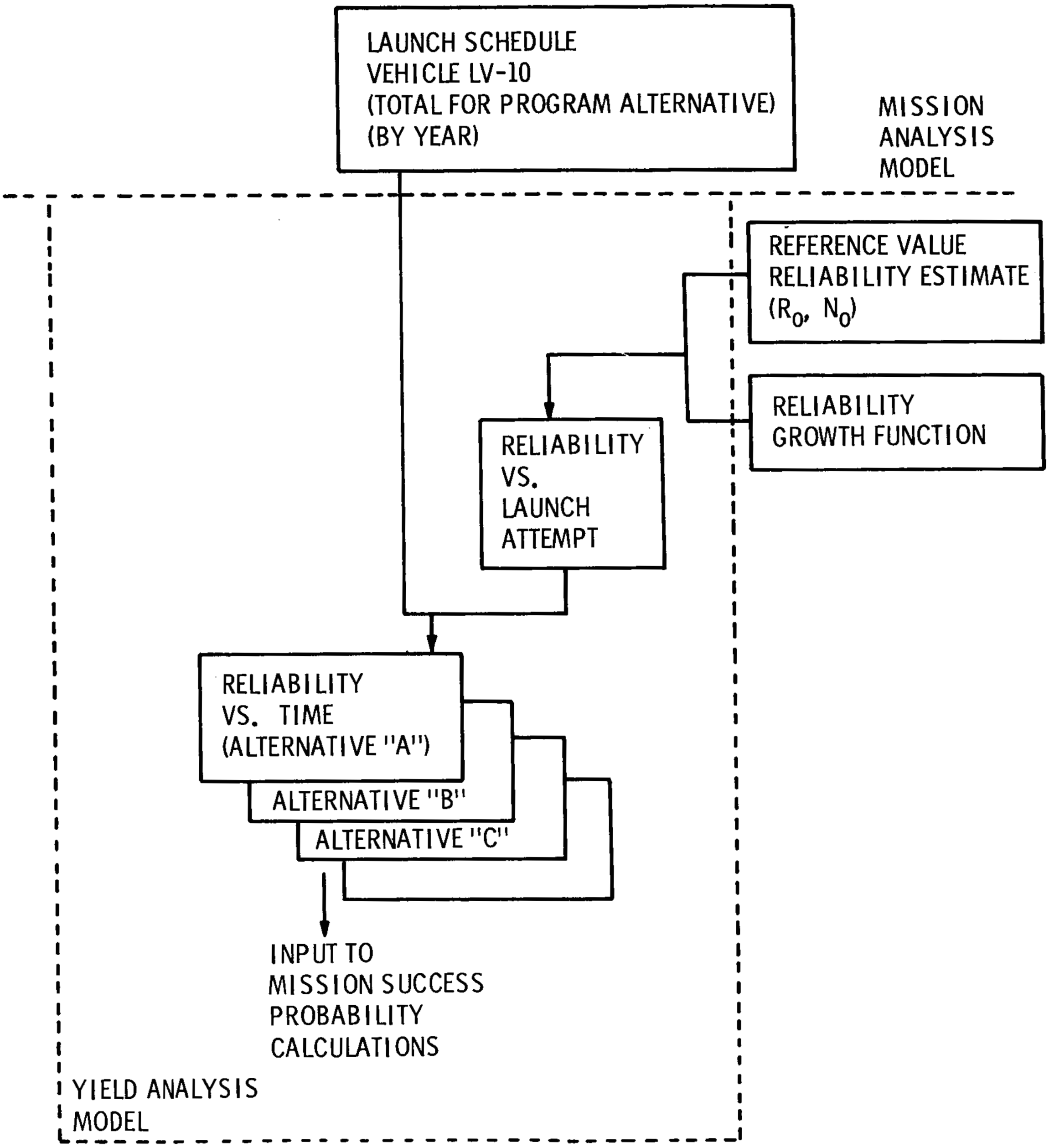

FIGURE V-2. LAUNCH VEHICLE RELIABILITY ESTIMATES

Launch vehicle reliabilities have been assumed to "grow" with succeeding launch attempts. The growth relationship has been assumed to be as follows:

$$R_i = R_\infty - \left[\frac{N_o}{N_i}\right]^\alpha \left[R_\infty - R_o\right],$$

where

R_o, N_o = Reliability estimate at a specified point (N_o) on learning curve,

R_i, N_i = Reliability at the N_i^{th} launch attempt,

R_∞ = Used in these analyses = 1.0 (Reliability with an infinite number of attempts and corresponding learning).

The following growth functions have been used:

$\alpha = 1/3$: for expendable vehicles or stages

$\alpha = 1/2$: for reusable vehicles or stages.

Curves of reliability versus launch attempt are then established for each launch vehicle or stage used in any of the program alternatives under study. Using the launch schedules for each program alternative, a schedule of reliability versus time is constructed for each launch vehicle, for each of the program alternatives. These same basic data are used throughout all program alternatives.

After similar procedures for space propulsion units, spacecraft, orbital operations, etc., reliability estimates for all elements are combined to arrive at a mission success probability for each launch attempt and mission attempt.

b. Definitions of Mission Success

The above procedure presupposes definition of the function that must be performed successfully for launch or mission success to be realized. From the standpoint of determining mission yield values, this will not always include all functions included in the mission profile. In some cases, for example, it has been assumed that safe return of at least one crew member is a prerequisite to realizing the information gain or yield from an exploratory manned planetary mission. On the other hand, where sustained operations have been established on a more nearly routine basis in an orbital station or lunar surface station, the yield from a particular crew's stay at the station is not dependent upon their safe return (information or gain from their stay would be obtainable through other means). In these cases, safe crew return has not been made a necessary function for mission success. In planetary missions involving convoys of vehicles, for example, it must be established which of the ships must complete the mission profile to obtain the desired yield from the mission attempt. Establishment of these "success definitions" is obviously an influential part of the mission yield calculations.

4. Equivalent Orbital Payload

There is naturally a desire to have a single yield parameter that is common to all missions and projects. In these analyses, "equivalent orbital payload," as described in Paragraph C, has been used as nearest to a "common denominator" for launch vehicle performance (short of the "worth" calculations, discussed in Chapter VII). The product of equivalent orbital payload (per successful launch) times launch reliability are summed for each launch vehicle and each program alternative, as a gross measure of productiveness. The orbital payload value, the reliability estimate, and the cost estimates used for this purpose are based on the launch vehicle configuration that would normally be used for low Earth orbit missions. For example, equivalent orbital payload for a Saturn V lunar mission would consider payload, reliability, and costs of the first two stages only. This is illustrated in Figure V-3, which also illustrates the compilation of "cost effectiveness" type yield measures; this procedure is discussed in a following paragraph.

5. Reusable Hardware Purchase Requirements

In order to compile program cost estimates, the CAM naturally requires information on quantity and schedule of necessary hardware purchases. For expendable hardware items, this is synonomous with equipment launchings. For reusable hardware elements, however, three factors determine purchase requirements: (1) attrition due to accidental loss (recovery failure probability); (2) inventory required to perform a specified launch rate; and (3) vehicle design life, or wear-out. These three factors have been combined in the launch vehicle analyses to insure that inventory is at all times adequate to perform the specified launchings. The resulting schedule of necessary purchases is then fed to the CAM as an output.

In all cases, this results in a vehicle inventory on hand at the end of the program. This represents residual capital; however, no credit for this residual has been reflected in the analyses to date, but should be incorporated in due time to reflect a more realistic picture.

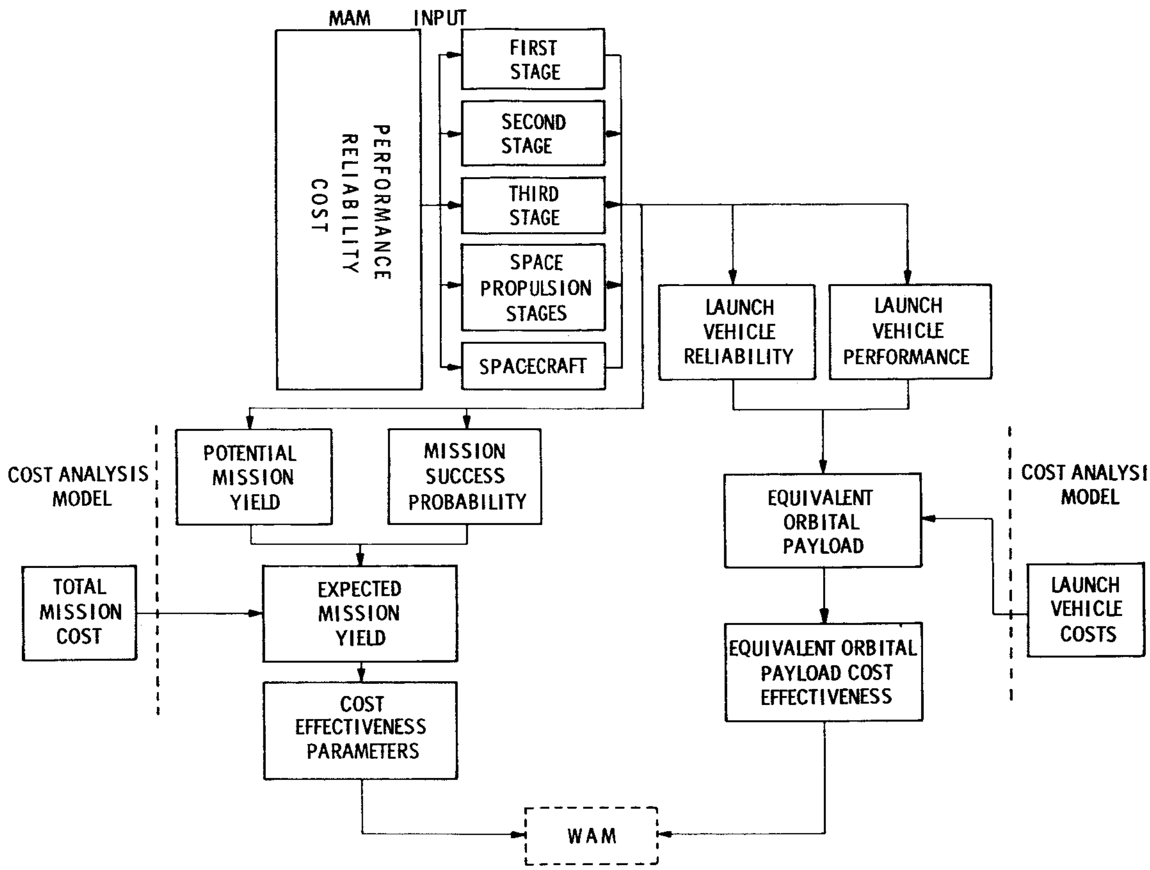

FIGURE V-3. YIELD ANALYSIS MODEL (YAM) - EQUIVALENT ORBITAL PAYLOAD AND COST EFFECTIVENESS PARAMETERS

6. Cost Effectiveness Parameters

Cost effectiveness parameters are the second major category of yield parameters used in the worth calculation. Their weight, however, is only about 10 percent of the total. The preceding paragraphs have described compilation of yield quantity measures. Within the CAM, costs are compiled for corresponding portions of the total program (as noted above for equivalent orbital payload). The combination of these two quantities, within the YAM (Figure V-3) gives measures of cost effectiveness in each area; e.g., cost per pound to orbit, cost per man-year on the Moon, etc. These are among the prime measures used in the WAM, comparing desirability of alternative programs.

7. Milestone Parameters

The third major category of yield parameters are the "milestones" selected as most significant, such as "year of first cumulative man-year in orbit," etc. In some cases, these milestones are derivable directly from the MAM (year of introduction of Post-Saturn launch vehicles, etc.), and require, within the YAM, the determination of expected probability of attaining each milestone as a function of mission attempts.

In others, however, the question is again faced whether credit should be logged on an "attempt" basis, or on a probabilistic basis. For example, logging credit for first manned lunar landing, or manned planetary flyby, on the date of first scheduled attempt has obvious drawbacks. The expected value or worth from mission attempts of this type is reflected, within the WAM, by multiplying "worth for a successfully met milestone" times the "calculated mission success probability." In addition to schedules of mission attempts, schedules of calculated mission success probabilities are output to the WAM.

C. INPUTS AND OUTPUTS

1. Internal Inputs - from Mission Analysis Model (MAM)

a. Mission Flight Plan - descriptions of mission objectives, and time periods in which mission attempts are to occur.

b. Mission Mode Selection - mission mode selected for each mission attempt, e.g., direct-flight to lunar surface, etc., including hardware descriptions.

c. Vehicle Flight Schedules - a detailed schedule of flight attempts, including designation of all major hardware elements, and type and technology levels for new hardware elements.

d. Propulsion and weight characteristics of all hardware elements.

e. Conceptual designs, weights, and performance estimates.

f. Logistics requirements for sustained manned operations in Earth orbit, on lunar surface, etc.

2. Internal Inputs - from Cost Analysis Model (CAM)

a. Subprogram area, and project;

b. Recurring versus non-recurring;

c. Launch vehicle costs versus spacecraft cost versus operational costs;

d. Customer, e.g., NASA, DOD, and others;

e. Fiscal year.

3. External Inputs

a. Reliability estimates (reference values) for:

(1) Launch vehicle stages,

(2) Space propulsive stages,

(3) Spacecraft,

(4) Orbital/space operations.

b. Reliability growth functions.

c. Estimates for reusable hardware elements:

(1) Recovery probabilities,

(2) Design life-time,

(3) Turn-around time.

4. Outputs to Cost Analysis Model (CAM)

Purchase requirements for reusable hardware elements.

5. Outputs to Worth Analysis Model (WAM)

The major outputs of the YAM are fed to the WAM for evaluation and for comparisons of the program alternatives under examination. The specific parameters selected to date as measures of mission yields are listed and defined in the following paragraphs. As noted previously, these parameters are categorized into three groups: "Quantitative" yield parameters, "milestone" parameters, and "cost effectiveness" parameters.

Space mission destinations have been grouped into four categories: Suborbital, orbital, lunar, interplanetary, and planetary. Where not otherwise stated, generalized parameters are applicable to each of these destinations. Where no comments are given in the following listing, the item is considered self explanatory.

a. "Quantitative" Yield Parameters

Unless otherwise stated, all quantitative yield parameters will be quoted on an expected value basis; e.g., value for successful mission-times-success probability. Compilation of yield parameter values for a given space program alternative are sub-categorized in a number of ways: e.g., (1) by individual launch versus project versus subprogram area; (2) by customer; e.g., NASA, DOD, Weather Bureau, etc.; (3) by launch vehicle type; or (4) by year, or other specified time increment.

(1) Equivalent Orbital Payload (Pounds)

A gross measure of space transport capacity or activity. The sum of orbital payloads over a specified time period, as if all launchings had been orbital missions, instead of the various missions as prescribed.

(2) Equivalent Lunar Man-Years

A gross measure of total transport capacity for each space program alternative; the total number of lunar man-years which would be accumulated if the resources of the entire program alternative were applied to the lunar area.

(3) Number of Instrumented Orbital Satellites Launched

(4) Mass of Instrumented Satellites Launched

(5) Number of Unmanned Lunar Probes Launched

(6) Total Number of Interplanetary Probes

(7) Total Number of Planetary Probes

(8) Total Number of Unmanned Flights (Orbital, Lunar, Interplanetary)

Includes all unmanned probes, plus unmanned logistics flights conducted in support of manned space operations.

(9) Total Useful Payload (Pounds) Delivered to Destination (Orbit, Lunar Surface, Planet Proximity, Planet Surface)

(a) The total mass delivered to the specified destination, exclusive of expended propulsive stage used in preceeding propulsive maneuver. Mass of return propulsive stage(s) and spacecraft is included.

(b) Optional alternative - the mass of useful cargo delivered to destination, exclusive of command modules, passengers, return propulsion, etc.

(10) Number of Sub-Orbital (Global) Man-Trips

(11) Cumulative Man-Trips (Orbital, Lunar, Planetary)

For a given project or subprogram area, the number of manned trips times number of men per trip.

(12) Cumulative Man-Years in Orbit (On Lunar Surace, On Target Planet Surface)

Product of number of people in orbit times the average stay-time, summed over a specified time period.

(13) Cumulative Man-Year in Vicinity of Planet

Time judged to be useful for data gathering in vicinity of target planet. Selection of "sphere" within which data gathering can be useful depends both upon the mission, and the time period of each mission attempt. For example, telescopic observations from some distance would be usefully made during an early flyby mission; however, a later landing mission would not find these observations useful.

(14) Mass of Scientific Equipment Delivered (Pounds) to Destination (Orbital, Lunar, Interplanetary, Planetary)

An estimate of the net weight of equipment to be used in scientific measurements and experiments. Normally, this will be the mass available over that necessary for the crew, housing, and sustenance of the crew, and provisions for their return to Earth.

(15) Scientific Man-Years in Orbit (On Lunar Surface, In Vicinity of Target Planet, On Planet Surface)

The estimated portion of the total man-years actually available for data collection or conduct of experiments. Excludes the man-hours or man-years estimated to be necessary for housekeeping, crew sustenance, etc.

(16) Number of Unmanned Probes (Orbital, Lunar, Planetary) Before 1976

(17) Number of Man-Years on Lunar Surface Before 1976

b. "Milestone" Yield Parameters

Those milestones affected by flight or mission reliabilities ("year of 10 cumulative lunar man-years," for example) are quoted on an expected value basis.

(1) Availability and Size of Largest Launch Vehicle

For each program alternative, the orbital payload capability, and year of introduction for largest launch vehicle.

(2) Availability of First Nuclear Propulsion Flight System

(3) Year of First Cumulative Man-Year in Orbit (On Lunar Surface, On Planet Surface)

(4) Year of First 10 Cumulative Man-Years in Orbit (On Lunar Surface, On Planet Surface)

(5) Year of 50 Cumulative Man-Years in Orbit (On Lunar Surface, On Planet Surface)

(6) <u>Year of First Low Altitude Laboratory With 3-Man Crew</u>

(7) <u>Year of First Manned Laboratory in Synchronous Altitude Orbit</u>

(8) <u>Year of First Orbital Station with 12-Man Crew</u>

(9) <u>Year of First "Low-g" Transportation System (Orbital, Lunar, Planetary)</u>

(10) <u>Year of Introduction of Global/Orbital Transport System</u>

(11) <u>Year of First Mars Surface Probe</u>

(12) <u>Year of First Solar System Escape Flight</u>

(13) <u>Year of First Manned Planetary Flyby</u>

(14) <u>Year of First Manned Planetary Orbiter</u>

(15) <u>Year of First Manned Planetary Landing</u>

c. <u>"Cost Effectiveness" Parameters</u>

(1) <u>Cumulative Average Direct Operating Cost (DOC) Payload to Orbit (Lunar Surface, Planet Surface) ($/Lb Payload)</u>

Cumulative expenditures for project of subprogram area, divided by cumulative total payload delivered (recurring costs, only).

(2) <u>Cumulative Average Total Operating Cost (TOC) - Payload to Orbit (Lunar Surface, Planet Surface) ($/Lb Payload)</u>

Same as (1), except on basis of <u>total</u> costs, including non-recurring costs.

(3) <u>Cumulative Average DOC - Equivalent Orbital Payload ($/Lb Payload)</u>

Cumulative launch vehicle costs (recurring) for all missions divided by equivalent orbital payload (cumulative) for all missions.

(4) Cumulative Average TOC - Equivalent Orbital Payload ($/Lb Payload)

Same as (3), except on basis of total costs, including non-recurring costs.

(5) Cumulative Average (DOC) for Orbital Missions (Lunar, Interplanetary, Planetary) ($/Man-Trip)

Cumulative expenditures for project or subprogram area, divided by cumulative man-trips for corresponding part of program alternative.

(6) Cumulative Average (TOC) for Orbital Missions (Lunar, Interplanetary, Planetary) ($/Man-Trip)

Same as (5), except on basis of total costs, including non-recurring costs.

(7) Cumulative Average Cost (DOC) Per Man-Year in Orbit (On Lunar Surface, on Planet Surface) ($/Man-Year)

Sum of recurring costs for project or subprogram area, divided by cumulative number of man-years for corresponding part of program alternative.

(8) Cumulative Average Cost (TOC) Per Man-Year in Orbit (On Lunar Surface) ($/Man-Year)

Same as (7), except on basis of total costs, including non-recurring costs.

D. TYPICAL RESULTS

Typical results from yield analysis of several typical space program alternatives are shown in Figure V-4 for illustration purposes.

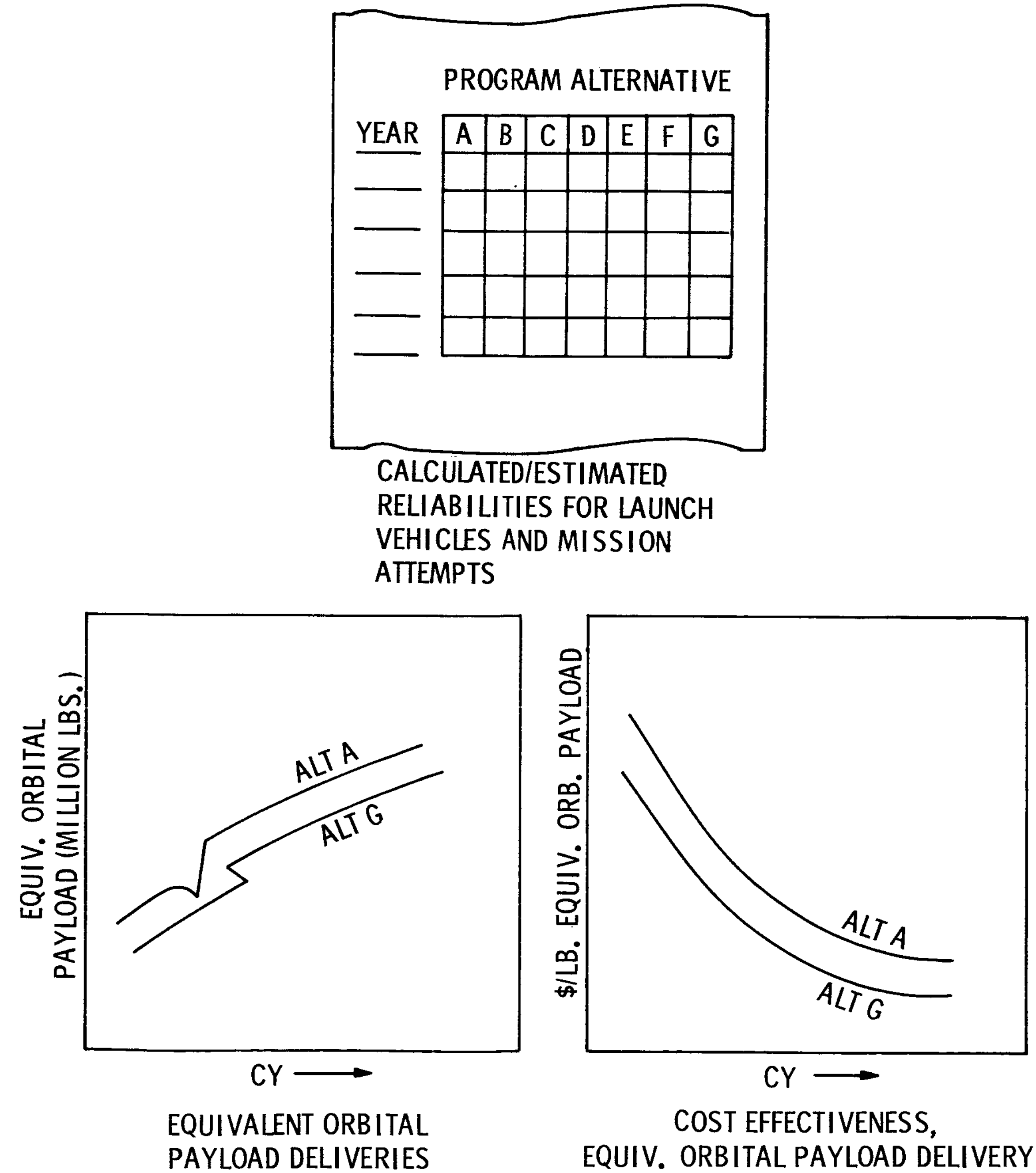

FIGURE V-4. TYPICAL YIELD ANALYSIS RESULTS

CHAPTER VI. COST ANALYSIS MODEL (CAM)

A. GENERAL INTRODUCTION

The task of the "Cost Analysis Model (CAM)" is to determine the funding requirements for the design, development, and operation of the hardware and projects that are the outputs from the "Mission Analysis Model (MAM)" and the "Yield Analysis Model (YAM)." The flow diagram shown in Figure VI-1 indicates the major tasks involved in accomplishing this objective. From the figure it can be seen that the external inputs to CAM are the hardware identifications, descriptions, and delivery schedules from MAM and YAM. From these descriptions and requirements the CAM calculates cost in four major categories: design and development, facilities, operational, and institutional support. Each of the four categories were costed separately with routines and procedures developed by the Future Projects Office of MSFC, MSC, and the RAND Corporation. From these computed costs, total program costs and funding can be determined and used to calculate the various efficiency and effectiveness measures of a space program.

This chapter will discuss the routines and procedures used in the cost calculations of the CAM. The applicable definitions, symbols, inputs, and outputs of the model are also discussed in this chapter.

B. SUMMARY OF CAM INPUTS

Following is a list of both external and internal inputs required for the CAM calculations:

1. Dimensions and weights of each hardware unit.

2. Schedule and quantity of each hardware item by code, project, and customer.

3. Date when each hardware item becomes operational.

4. Identification of reusable hardware items.

5. Schedule of refurbishment and procurement for each of the hardware items in 4 above.

6. First unit cost for each hardware item.

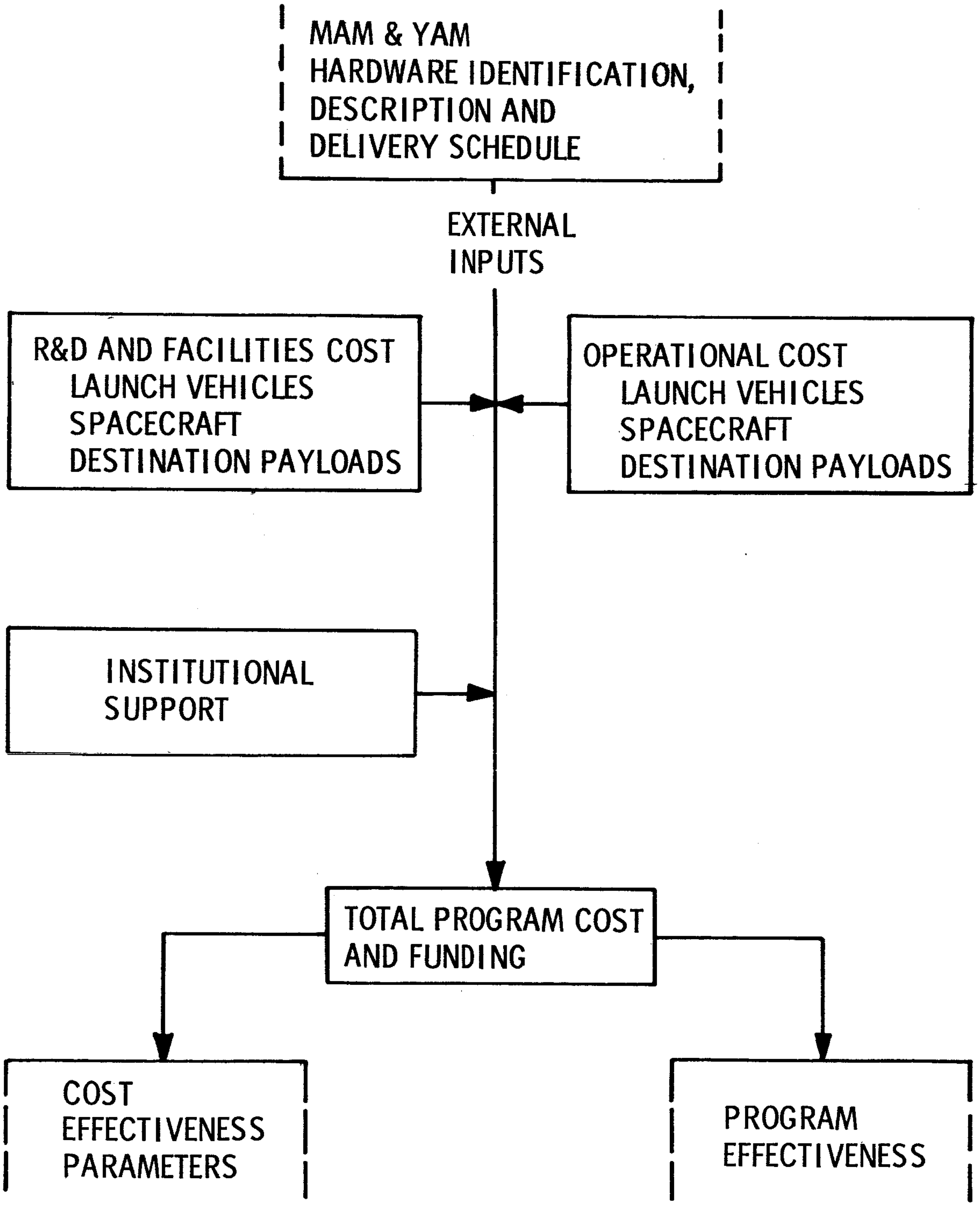

FIGURE VI-1. COST ANALYSIS MODEL (CAM) MACRO-STRUCTURE

7. Refurbishment cost for each reusable item.

8. Learning curve slope for each hardware item.

9. Funding leadtime assumptions for the R&D cost for each item.

10. Funding leadtime assumptions for the operational cost for each hardware item.

11. Present budget exclusive of institutional support.

12. Present Institutional support cost.

C. CALCULATION PROCEDURES

The cost projections associated with the development and operation of advanced space flight systems is one of the more demanding tasks of this calculation procedure. The classical method of cost projections in the past has been to base cost on the development and operation of the necessary systems to meet the objectives of a specific mission. In the cost projections of a total space flight program, as described in this report, this method is not adequate. Special considerations must be given to both the development and operational categories if accurate costs are to be determined. Figure VI-2 is a flow diagram that shows in some detail the factors that are considered in these various cost calculations. The figure shows that there are three cost subroutines that make up the CAM: R&D and facility, operational, and institutional support. Each of the three subroutines will be discussed separately below.

1. Research and Development Cost

The hardware items output by MAM are identified and classified into three categories: items that can be used as they are and require no modification; items that require modification; and items that require complete development. The Saturn/Apollo hardware and some operational space vehicle systems are in the first category. It was assumed that in this category the remaining runout cost, if any, from 1965 on would be charged as R&D requirements. These costs are obtained from the project offices and are put directly into the R&D Cost Submodel. The second category, items that require modification, requires a detailed description of the modification and a schedule of when the hardware is needed. This category is one of the most difficult to cost since most cost models are based on computing complete development cost and are not applicable to costing modifications. Although the costing of new items requires by far the

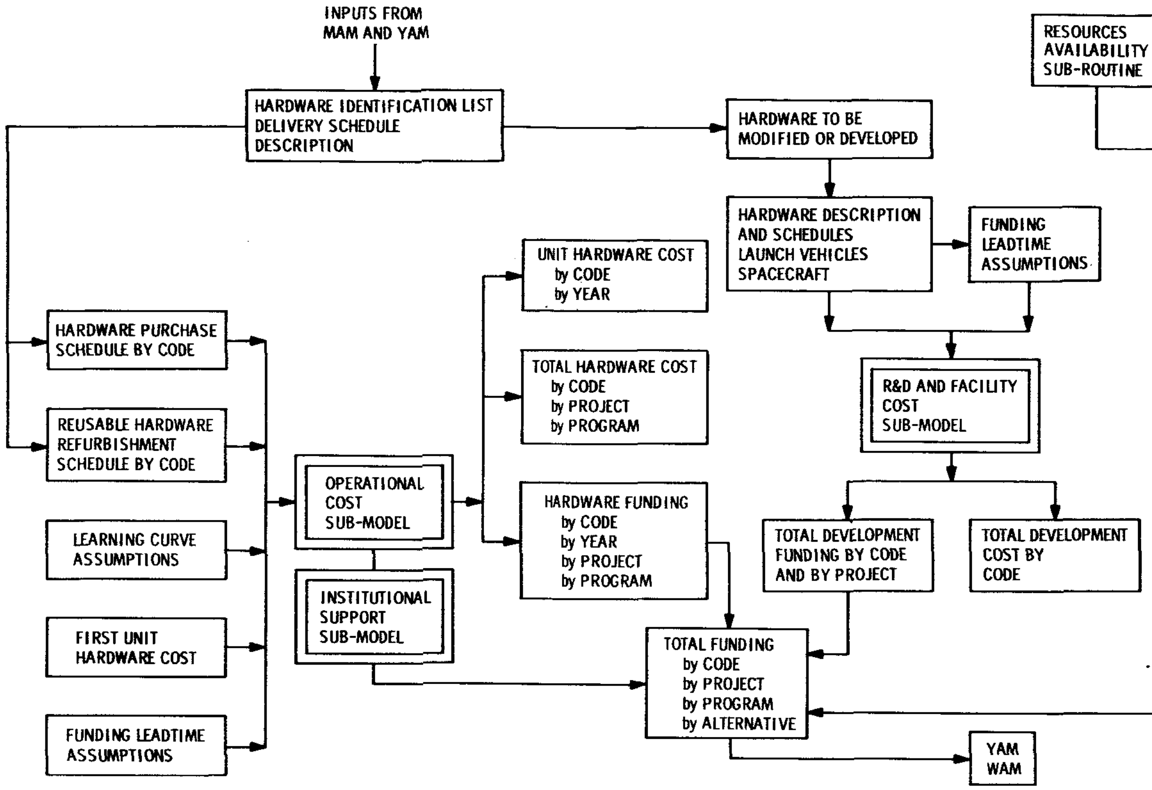

FIGURE VI-2. COST ANALYSIS MODEL (CAM) CALCULATION PROCEDURE

most effort, the task is relatively straight forward. This is true because most of the past work has been done in the area of R&D costing. Because of the varied physical characteristics of many hardware items and the available techniques for determining R&D cost, the items in the last two categories were divided into three classes: launch vehicles, spacecraft, and destination payloads. The techniques and routines used in each of these classes will be discussed separately below.

a. Launch Vehicles

For the last three years a comprehensive effort has been made by the Future Projects Office of MSFC, with the help of aerospace contractors, to develop a generalized launch vehicle cost model that could cost both present and proposed launch vehicle systems. This effort has resulted in developing one of the most advanced and complete models of its type in the aerospace industry today. The model is now operational on the IBM 7094 computer in the MSFC Computation Laboratory and is the source for most of the research and development and facility cost of the launch vehicles. The structure and cost estimating relationships of the model span the technologies up to 1990, and include liquid, solid, and nuclear systems.

A complete description of the model structure, estimating relationships, and cost categories can be found in the General Dynamics, "Launch Vehicle System Cost Model," Technical Report No. FZM-4154, dated June 15, 1964. Reusable as well as expendable vehicle systems can be costed by the model. The launch vehicle cost model uses as inputs the hardware descriptions and schedules that are output by both the MAM and YAM. Funding leadtimes are also inputs to the model so obligational funding can be determined.

All facilities necessary to manufacture, test, and launch the vehicles are included in the research and development cost category. In cases where a new facility is needed, the launch vehicle cost model can be used to obtain these costs. If a modification on an existing facility is needed, a point estimate can be made and input to the model.

In addition to the launch vehicle cost model, Post-Saturn and Reusable Orbital Transport Vehicle Studies are utilized in the costing of advanced vehicle systems.

Vehicle systems that require modifications are difficult to cost with the launch vehicle cost model; therefore, point estimates for these costs are obtained from advanced studies, project offices, contractors, and from experienced personnel from the Future Projects Office and the RAND Corporation. These point estimates are made largely on modifications of the Saturn/Apollo hardware and are considered to be consistent with present estimated costs of these systems.

The costs computed by the launch vehicle cost model, as well as the point estimates, will consider the state of the art at the time of the new system development, i.e., the Post-Saturn costs, will reflect the knowledge gained from the development of the Saturn vehicles.

b. Spacecraft

This portion of R&D costing is the most difficult to calculate. This is true for two reasons: first, there is little history or few systems that are applicable for extrapolation; and second, the state of the art in spacecraft costing is not well established. Presently, there is no good general spacecraft cost model that can cost the wide variety of technologies required for this calculation procedure. Because of these reasons, the Future Projects Office relied heavily on MSC and the RAND Corporation for contributions in this area. The Apollo systems are used as the base for estimating the cost of advanced spacecraft systems, and the launch vehicle cost model is utilized to aid in costing of spacecraft propulsion systems. The advanced studies that have been conducted, both in-house and by contractors, are also utilized as a source for obtaining cost information that is applicable to advanced spacecraft systems. The RAND Corporation and MSC work together closely to insure as much consistency as possible in developing spacecraft cost information. This approach accounts for orderly development of spacecraft cost information. In the case of Apollo systems, run-out cost for 1965 on are estimated by MSC and are input to the R&D submodel. The facility cost necessary to develop and test the systems are also included in the development cost.

c. Destination Payloads

The destination payload items are divided into two classes: major systems that are to operate at the destination, and supplies to maintain the operation at the target facility once it has been established. The first class consists of the major cost of this category, of such items as MOLAB, shelters, power supply modules, communication systems, etc. Since little historic data are available on the development of these systems, studies that have been conducted by MSFC, MSC, and other agencies are utilized to establish the baseline cost for the systems. These baseline costs are then adjusted or modified to be consistent with the objectives of the mission under consideration. In some cases, where no data are available, point estimates are made. These estimates, as well as the adjusted baseline costs, consider an orderly development of the systems with time. For instance, this concept of costing allows the development cost of the planetary systems to reflect the lunar developments and technology.

The second class, i.e., the supplies that are necessary to maintain the operation at the target sight, is considered to be largely off-the-shelt items. These items consist of such supplies as life support, fuel, and housekeeping supplies. It is assumed that no development cost is to be charged for these items but a cost is charged for the packaging of these payloads. This packaging consists of specially designed modules to protect the supplies in transit and for storage at the destination.

d. Proration of R&D Cost

After the R&D and facility costs are calculated for each hardware item they have to be assigned to the appropriate projects. Since most systems are used in more than one project, a decision has to be made as to how these costs should be allocated between the projects. Costs are prorated among the projects that are to use the system on a usage basis, i.e., each project that uses the system is charged a percentage of the R&D cost equal to the ratio of the number of systems used in the project to the total number of systems used in the program. All of the R&D is prorated presently by this scheme with the exception of the following:

(1) Costs are not split between customers (NASA, DOD, etc.), but are charged to the projects of the customer having the initial requirement.

(2) All costs of the Apollo hardware are charged to the Apollo mission.

(3) The reusable orbital transport and global range/orbital transport costs are charged to the orbital subprogram.

(4) The uprated Saturn V is charged to the lunar and planetary subprogram according to usage.

(5) The Post-Saturn vehicle is charged to the lunar and planetary subprogram according to usage, with the exception of the third stage, which is charged only to the lunar subprogram.

After the proration of the R&D costs is completed, the costs are spread to obtain the obligational funding requirements. The spreading functions account for the duration of the development program and the year when the first funds must be committed to meet the operational schedule. The outputs of the R&D cost model consist of total R&D cost and funding by hardware item, project, mission, subprogram, and program. These costs are then added to the operational and institutional support costs to obtain total cost and funding by project, subprogram, and program.

2. Operational Cost

Normally one of the most time consuming tasks in a procedure like this is the determination of operational cost. The magnitude of this problem is caused by the number of different hardware items required to perform a space program and the different usage requirements between the alternative programs. The calculations themselves are relatively simple, once the proper inputs are obtained, but are repetitious and time consuming. Therefore, it was decided to develop and program, on the IBM 7094 computer, a routine to compute the operational cost. The details of this submodel are explained in a subsequent paragraph. With the availability of this computerized routine, the major emphasis was devoted to the development of accurate inputs for the submodel, and the organization of the outputs for use by subsequent models within the PAEP. The input requirements and sources, computer logic and outputs, and the organization of CAM outputs are discussed in the following paragraphs, and reference is made to the operational cost model portion of Figure VI-2.

a. Operational Cost Inputs

There are two general types of inputs used in the operational cost calculations: those generated by other models within the PAEP, and those generated as a part of the cost analysis task.

The external inputs to CAM are generated primarily by the MAM and YAM of the PAEP. The MAM identifies each item of hardware required by the total space program, and gives the yearly usage rate. In the case of expendable hardware, this becomes a direct input to CAM. In the case of reusable items of hardware, this information is an input to YAM, which calculates the number of new items that must be purchased and the number of refurbishments required to maintain the inventory necessary to fulfill the mission requirements.

With the information given, as discussed above, it is necessary to compute within CAM the other inputs required to calculate operational cost. This information is shown in Figure VI-2 and includes the first unit cost, learning curve assumptions, and the funding leadtimes required to convert cost to yearly funding requirements.

First unit costs are obtained from many sources, depending on the item and its present design status. In the case of existing hardware, systems under development, and modified systems, the best estimates available are obtained from the program offices of MSFC, MSC, or other NASA elements. In the case of spacecraft or destination payloads, which are in the conceptual design phase, estimates are obtained from contractor studies or point estimates are made based on the extrapolation of existing systems. In the case of conceptual launch vehicles, the estimates are obtained from contractor studies or by using the operational cost relationships of the launch vehicle cost model; whichever is considered most applicable. The launch vehicle cost model relationships consider several categories of cost that affect operational cost, e.g., hardware, acceptance tests launch operations, sustaining engineering, tooling, etc., and were considered the best estimates available.

The learning curve assumptions, in terms of the unit number at which learning begins and the rate of learning, are obtained from an analysis of the hardware item involved and the total usage of the item over its operational lifetime. These assumptions are obtained, where possible, from project offices; but, in the case of conceptual systems, they are obtained by comparing the systems being analyzed to similar systems for which past history and experience can be applied.

Leadtime assumptions, or spread functions, required to determine funding requirements in terms of obligational authority, are developed in the same manner as the learning curve information. All of these inputs are then used in the operational cost submodel as explained in the next paragraph.

b. Operational Cost Submodel

A potentially large time consuming task in the CAM is the mechanics of computing the operational cost once the inputs are obtained; it is not difficult but is tedious and repetitious. For example, each alternative program can involve more than 100 hardware items, each of which requires unique inputs. Within each alternative there is hardware commonality among projects. Therefore, it was considered advantageous to develop a computerized routine with the following characteristics: simple to program and checkout; simple to input, but with flexibility; short run-time; and output formats that can be used to obtain many different and useful groupings of the results.

This effort resulted in a submodel that can accept up to 1000 hardware items and projects per alternative, 25 different spread functions, and unlimited operational program length. The inputs required for each item are learning curve slope, unit number at which learning begins, first unit cost, spreading function, leadtime, and the project usage versus time. With these inputs, the submodel performs the following basic operations: for a given hardware item, it sums the total requirements for a given year, enters the proper learning curve, and computes an average cost per unit for the year. This average cost is multiplied by the usage to obtain total cost by year, and applies the proper spread function to obtain total funding. For each project, it computes the usage and, by applying the average cost, computes the total cost and funding of the item as required by the project.

In summary the outputs of the submodel are as follows:

(1) Total units required by year for each project and total program.

(2) Average unit cost by year for each hardware item.

(3) Total cost by hardware item and year for each project and the total program.

(4) Spread cost or funding by hardware item and year for each project and total program.

c. Operational Cost Outputs of CAM

The output data are organized into specific formats, as follows: the different items of hardware are combined to give project cost and funding by year. These project data are combined into the major subprogram areas of orbital, lunar, and planetary; and these are then combined to give total program plan data. There are several special groupings of the data as required for special effectiveness, and efficiency calculations, and these include: total launch vehicle cost and funding, total spacecraft cost and funding, and orbital equivalent cost.

The operational funding information discussed here is combined with the R&D and facility funds to obtain total funding requirements at the subprogram and program level. These total funding data are output to the WAM, YAM, and resources availability routine as required.

3. Institutional Support

a. Introduction

The costs computed by the R&D and facility and operational submodels accounted for only the cost incurred by contractors to develop, test, and operate the hardware systems. NASA's cost for in-house basic research, and support and management of the approved programs were not included in these submodels. For the purpose of PAEP, these costs are classified as institutional support costs and are made up of salaries and plant operations for Headquarters and all the Centers. In an attempt to include all costs in the PAEP results, the NASA budgets for past years were analyzed to determine a method that could project institutional costs as a function of NASA budget. The procedure that is utilized at the present time is discussed below.

b. Calculation Procedure

The above mentioned analysis indicated that the institutional support costs increased with increasing NASA budget; therefore, a growth function was developed as follows:

$$IS = P\,(1 + R)^{n-1} \qquad (1)$$

where:

IS = Institutional support cost in any year

P = IS for FY 1965

R = Growth rate

n = Fiscal year being calculated minus the base year, 1964.

The funding requirements of the programs analyzed by PAEP indicate a general growth with time through about FY 1978, at which time the budget declines. This decline is the result of structuring the programs through 1990 only, and the lack of new developments in the later years. It was assumed, for the purpose of institutional support calculations, that the institutional support is a constant cost over this time period. Therefore, the above equation is used for the period $1 < n \leq 14$, and for $n > 14$ the equation becomes:

$$IS = P\,(1 + R)^{14 - 1} \qquad (2)$$

The remaining parameter of this equation is the growth rate that may assume any value. As a first approximation for PAEP, R was determined as follows: the institutional support cost of FY 1962 ($n = 7$) for each program was calculated by:

$$IS\,(1972) = P\left[1 + \left(\frac{\frac{B_A}{B_P} - 1}{4}\right)\right] \qquad (3)$$

where:

B_A = Average NASA budget of total program

B_P = Present NASA budget exclusive of IS

The resulting value of institutional support (1972) is substituted into Equation (1), and the value of R that is used for the program is computed.

This procedure is used at present as a first approximation and will be modified as better insight is gained, or a better method is derived.

D. SUMMARY OF CAM OUTPUTS

Following is a list of CAM outputs required by other models of PAEP to compute effectiveness and efficiency measures:

1. Unit cost of each code by year.
2. Total operational cost of each hardware item.
3. Operational funding for each hardware item by project by year.
4. Operational funding for each project by year.
5. Operational funding for each mission by year.
6. Operational funding for each subprogram by year.
7. Operational funding for each program alternative by year.
8. R&D cost by hardware item.
9. R&D cost by project by year.
10. R&D funding by project by year.
11. R&D cost by mission by year.
12. R&D funding by mission by year.
13. Institutional support cost by year by alternative.
14. Institutional support cost by year by subprogram.
15. Total subprogram funding by customer by year.
16. Total subprogram cost by customer by year.
17. Total alternative cost by customer by year.

18. Total alternative funding by customer by year.

19. Total operational vehicle cost by year.

20. Total vehicle R&D cost by year.

21. Total vehicle R&D funding by year.

22. Total operational vehicle funding by year.

23. Total vehicle cost by alternative by year.

24. Total vehicle funding by alternative by year.

25. Total orbital equivalent cost by alternative by year.

E. RESOURCES AVAILABILITY SUBROUTINE

1. General Problem

A necessary part of the analysis of long range plans for space programs is the consideration of resources, which may act as one of the major constraints or selection criteria in developing a reasonable long range plan. Resources may be identified as follows: funds, materials, manpower, and facilities. Within each of these broad categories of resources there are many facets that must be considered before a meaningful evaluation of long range plans can be effected. The general approach presently being followed in the analysis of resources is to separate the problem into two segments: the projection of resources availability expected and the determination of expected expenditures for a space program alternative plan under study.

In the area of resource availability, the analysis depends on historical data and the projected trends for each resources class. To arrive at meaningful results, each category of resource must be studied in some detail. For example, funding availability is determined from the analysis of the overall national economical growth (GNP), the Federal budget, and the allocations of the Federal budget to space activity. The availability of materials is dependent on natural resources, the priority given to demands for consumer and producer durable goods, transportation, power production, agriculture, etc. Similarly, manpower availability is dependent on the population's growth, educational facilities, and demands of other industries. There are many agencies studying these resource problems, and predicting trends for the future.

In determining resource requirements, methods must be developed to analyze space programs in terms of the impact on resources. From the description of space program given by the Program Structure Identification Tables and the MAM, the requirements for development of new hardware items must be analyzed in light of types of materials, the state of the art advancement, numbers and types of researchers, production methods, facilities, skills, etc. The CAM identifies the funding required by type, i.e., R&D and operational.

Because of the complexity of the problem and because of the time constraints involved in this study of long range plans, the resources problem was not analyzed in the depth discussed above. One area, expected availability of funds, was selected and analyzed in this study. It was felt that this is one of the most critical resources, and that a rough method of prediction could be developed in the allotted time, and would allow a preliminary test of the reasonableness of the alternate space programs. This method is explained below.

2. Present Resource Analysis

The funding resources that could potentially be available to NASA were calculated from a projection of Gross National Product (GNP) under the following assumptions:

a. Projectives are based on 1964 dollars.

b. GNP would grow at a constant 4%/year.

c. NASA's share of GNP is a constant percentage.

With these assumptions the projected GNP is calculated by year as follows:

$$(GNP)_n = GNP\ (1.04)^{n-1}$$

where:

$(GNP)_n$ = GNP in any year, n

GNP = present (1964) value

n = year being calculated (year of concern 1964)

From this projection of GNP, the NASA budget is calculated from:

$$(\text{NASA budget})_n = (P)(GNP) = (P)(GNP)(1.04)^{n-1}$$

where:

$(\text{NASA budget})_n$ = NASA budget in any year, n

P = percent of GNP that is NASA budget.

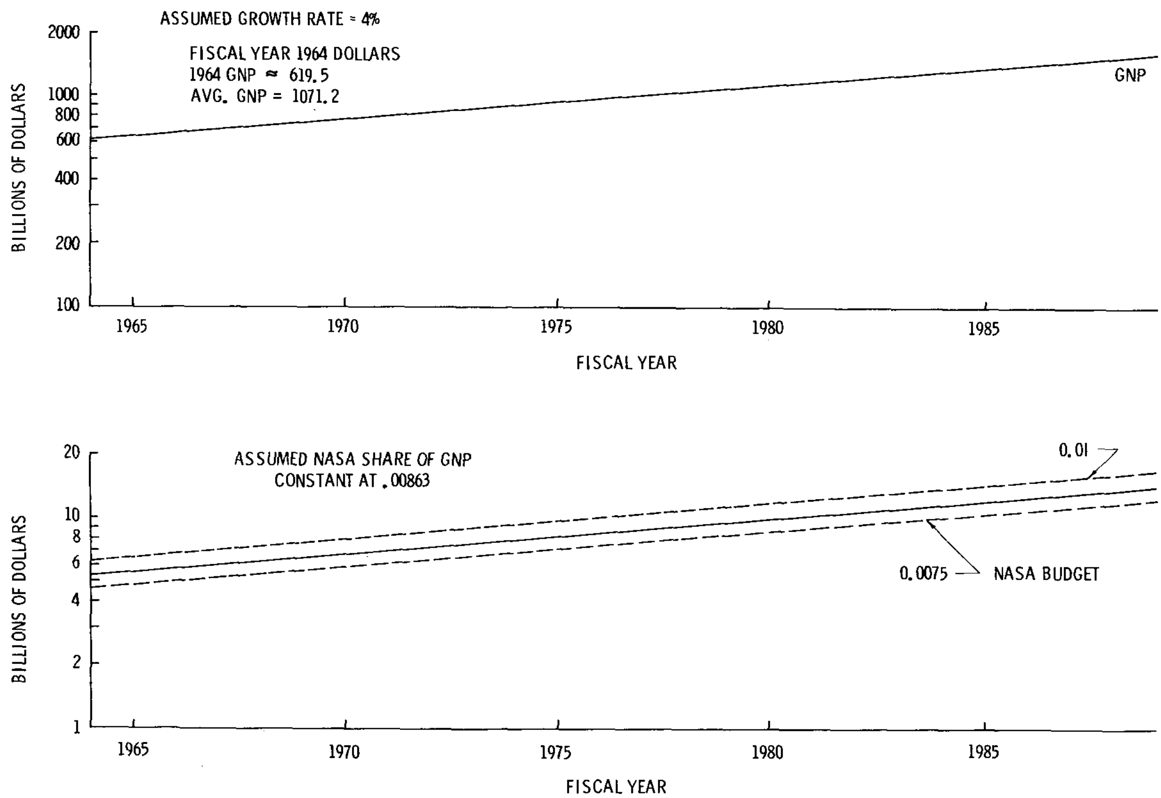

FIGURE VI-3. PROJECTED GROSS NATIONAL PRODUCT (GNP) AND NASA BUDGET

The CY 1964 GNP is estimated at $620 billion, and with the NASA budget of $5.35 billion, the FY 1965 percentage was calculated at 0.863% of the GNP. With the uncertainty involved, it was decided to compute a band of NASA funding available assuming upper and lower limits on the percentage figure. For the purpose of this study, these limits were set at 0.75% and 1.0% respectively. Figure VI-3 shows the result of these calculations of GNP and NASA budget.

The test of reasonableness of the postulated space program was accomplished by superimposing the projected NASA budget on the funding requirements resulting from the CAM. From information of this type, decisions can be made on whether to adjust the missions within the space program so that the funding requirements fall within these constraints.

As mentioned earlier, this is only one facet of the resources problem and can only be used as a rough measure. As the more detailed and sophisticated tools become available they will be integrated into this analysis technique.

CHAPTER VII. WORTH ANALYSIS MODEL (WAM)

A. INTRODUCTION

The purpose of the "Worth Analysis Model (WAM)" is to correlate the "program yield" with the "program objectives." Thus, a yardstick becomes available that can be used to measure the degree these program alternatives are expected to satisfy the selected program objectives. If this program worth is combined with the program total cost, a measure of program effectiveness is available, establishing a common basis for program comparison. The relationship of the WAM with respect to the other models of the Program Analysis and Evaluation Procedure (PAEP) is shown in Figure II-1 in Chapter II.

One of the ultimate aims of worth analysis is to provide a means for synthesizing an optimum space program for the nation. The word "optimum" is used in a very gross sense and it is clear that worth analysis alone, as discussed herein, cannot be expected to lead automatically to an "optimum" program. However, it is expected to be used as a valuable tool by those engaged in synthesizing programs for the purpose of gaining a better insight into some of the factors that influence the apparent worth of a program.

In synthesizing a program one might begin by asking: are there any projects or activities in space that are essential to national security or survival? This question can be answered only on a case-to-case basis and might result in some overriding constraint in a worth analysis and thus represents the first step. Those features of a program, which are essential to national survival or national security, represent the minimum baseline program that is acceptable. Once a plan for the minimum baseline is agreed upon, which is in itself a formidable task, the worth analysis tool can be applied to the problem of deciding which of those "nice to have" features in a space program are actually nice enough to be worth the cost.

The analysis described in detail herein has a serious shortcoming with regard to program synthesis in that it gives, by itself, no credit for a balanced program with activities in several areas. One would expect that there will be a synergistic effect of interactions of activities in various areas such that the whole space program will be greater than the sum of its parts. Without such considerations, use of this type of a worth analysis for synthesis of an optimum program would tend to result in a program with all activity placed in the area that appears to deliver the most worth, unless several areas deliver approximately equal worth. In that case, the individual program yield indices will be modified by a devaluation function, which will reduce the obtained worth with increasing numerical values of yield. This characteristic would then result in the optimum program having a reasonable number of projects in several subprograms, such as orbital, lunar and planetary.

B. GENERAL DISCUSSION OF APPROACHES

The key assumption in the WAM is the hypothesis that a group of suitable measurements of yield are representative variables to be used in establishing a worth function. If this is true, each program will be assigned a worth function, based on value judgments of knowledgeable people, of a type that adequately correlates program yield and program objectives.

A typical problem to be solved in this connection is, e.g., how to measure the "prestige value" of a number of space projects. We assume that this prestige can be assessed by primarily two groups of measurements of yield:

1. Yields, which are a measure of transportation quantities (or volumes), such as total mass delivered to Earth orbit, lunar surface, or planetary surfaces; number of man-round-trips to various destinations; total number of launches of unmanned and manned space vehicles, etc.

2. Milestones accomplished and the time at which they are accomplished. Individual space program goals can easily be identified and correlated with time. This analysis includes an estimate of the probability of mission success as a function of number of mission attempts, observing hardware commonality. Each milestone can be listed with respect to a desirable early target date. The worth contribution of this event can now vary with the number of years expired between the year of accomplishment and the target date.

In this fashion the total prestige is measured by a large number of representative smaller events, demonstrating successful space flight operations, open for everyone to see and thus producing a prestige value.

In a similar way, not only the political worth, but also the military, economical, scientific and technological worth of individual programs can be estimated. It is important to note that the relative worth of an alternative space program, with respect to another alternative, is of primary interest and not the absolute value of worth, which would be an almost impossible task. Consistent treatment of program alternatives rather than the accuracy of one particular program is important here.

The dimension of a "unit worth" is one which has to be defined in each particular worth model. One choice would be to assign the largest program under consideration a worth value of unity and assign all other alternatives worth values in percent of the maximum. A second way is to set no maximum numerical value, but express one program worth by another in multiples of worth, e.g., Program B has 1.5 times the worth of Program A.

In general, the definition of the unit worth depends on the worth estimating relationships chosen. It is not very crucial within the WAM which one is chosen, as long as it is properly interpreted.

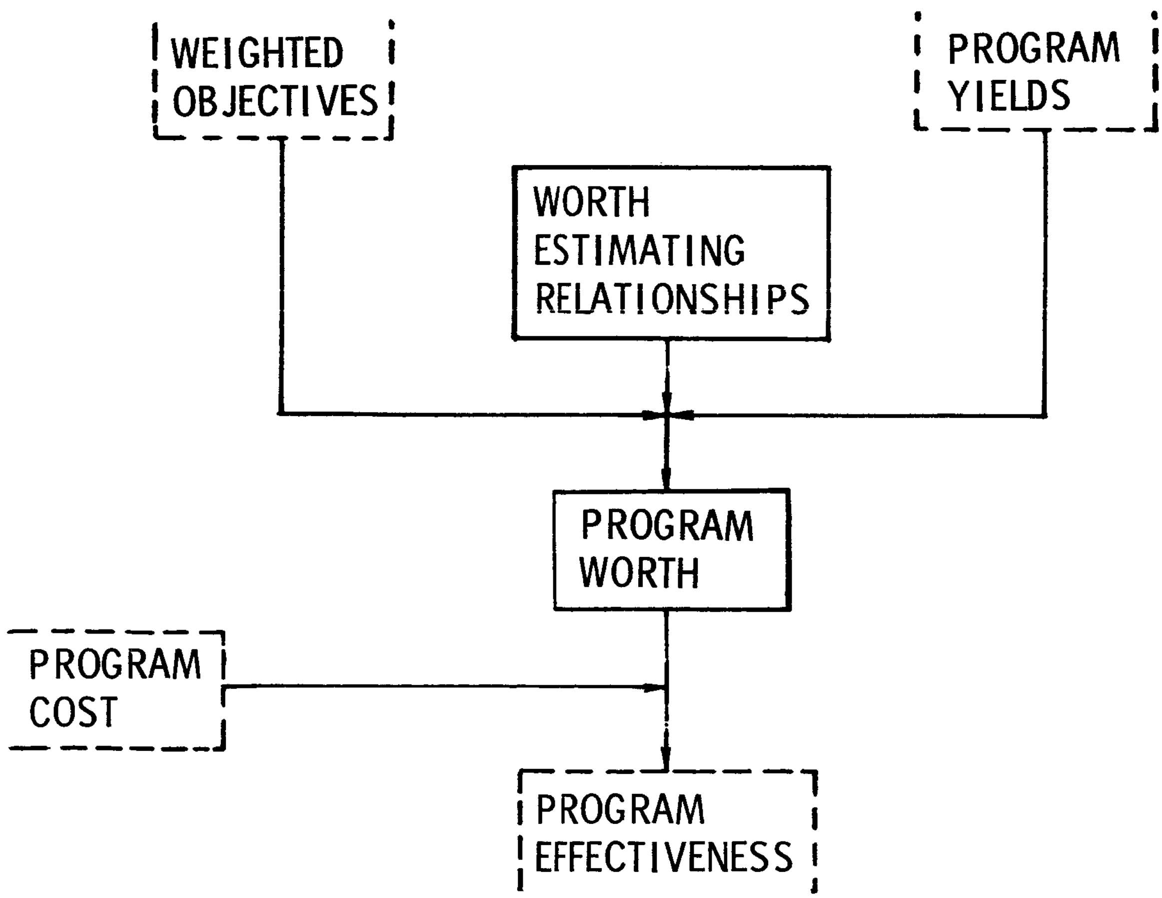

FIGURE VII-1. WORTH ANALYSIS MODEL (WAM) MACRO-STRUCTURE

The basic structure, as well as the procedure selected for the WAM, shown in Figure VII-1, can be a controversial subject. In order to investigate the sensitivity of the features and relationships selected on the results, three different approaches were tried. The first approach (A) is the most simple one and can be applied by one man within a few hours requiring only slide rule calculations. The other two approaches are machine calculations of more elaborate worth estimating relationships. The second approach (B) requires a relatively higher degree of group judgment than the third approach (C), where essentially the entire model is computerized. However, in all methods experience or value judgment factors can easily be varied to determine sensitivities. The different features of the three approaches, to be discussed in detail in the following paragraphs are summarized in Table VII-1.

TABLE VII-1. WORTH ANALYSIS MODEL - MAJOR FEATURES

	APPROACHES (with different levels of sophistication)	A	B	C
Model Features	FIVE PROGRAM OBJECTIVES	X	X	(X)
	TWENTY PROGRAM OBJECTIVES		(X)	X
	HAND CALCULATED	X		
	COMPUTERIZED		X	X
	LINEAR RELATIONSHIP BETWEEN YIELD AND WORTH	X	(X)	
	NONLINEAR RELATIONSHIP BETWEEN YIELD AND WORTH		X	X
	MAXIMUM WORTH LIMITED			X
	MAXIMUM WORTH NOT LIMITED	X	X	
Output Characteristics	TOTAL PROGRAM WORTH	X	X	X
	ANNUAL PROGRAM WORTH		X	X
	TOTAL PROGRAM EFFECTIVENESS	X	X	X
	ANNUAL PROGRAM EFFECTIVENESS		X	X
	( ) INDICATES SECONDARY CHOICE			

C. APPROACH A

This approach is characterized by the assumption of linear relationships between yield and worth. Furthermore, the number of objectives, as well as the number of yield indicators used, was kept small in order to be able to compute worth values by hand.

This simple model can be termed a pilot model for the preliminary evaluation of program alternatives, and is structured around the following number of variables:

1. Program objectives = 5,
2. Terms in total worth equation = 31,
    a. Quantity terms = 23,
    b. Cost effectiveness terms = 4,
    c. Milestone terms = 4,
3. Different yield indicators = 22,
    a. Quantity yield indicators = 14,
    b. Cost effectiveness yield indicators = 4,
    c. Milestone yield indicators = 4.

The weight factors used for the five major objectives were:

1.	Political	$\theta_1 = 20$
2.	General Welfare (economical)	$\theta_2 = 35$
3.	National Security	$\theta_3 = 15$
4.	Scientific	$\theta_4 = 20$
5.	Technology (transportation)	$\theta_5 = 10$

Table VII-2 shows the matrix selected for Approach A. It shows the correlation of yield indices with the program objectives, and indicates which of the yield indices (y) were selected to represent the program yield in the worth estimating relationships.

TABLE VII-2. OBJECTIVE - YIELD CORRELATION MATRIX (APPROACH A)

		TOTAL PROGRAM								ORBITAL SUBPROGRAM							LUNAR SUBPROGRAM			PLANETARY SUBPROGRAM				
		y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	y_{11}	y_{12}	y_{13}	y_{14}	y_{15}	y_{16}	y_{17}	y_{18}	y_{19}	y_{20}	y_{21}	y_{22}	YIELD PARAMETERS
WORTH GROUP	WEIGHTING FACTOR	Total Program Expenditure	R&D Experditures	Total Equivalent Mass Orbited	No. of Space Probes Launched	No. of Space Probes Launched before 1975	Global Transportation Available	Largest Carrier Available	Nuclear Vehicle Available	Total Mass in Earth Orbit	No. of Unmanned Satellites in Earth Orbit	No. of Man-Years in Earth Orbit	No. of Man-Trips into Earth Orbit	No. of Scientific Lbs in Earth Orbit	Direct Operating Cost for Cargo to Earth Orbit	Direct Operating Cost for a Man-Round-trip to Orbit	No. of Scientific Pounds to the Moon	No. of Lunar Man-Years by 1975	Total No. of Lunar Man-Years	No. of Scientific Lbs to the Planets	Year of First Manned Flyby	Year of First Manned Landing	Total No. of Planetary Man-Years	
		A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}	YIELD PARAMETER WEIGHT FACTORS
W_1	θ_1					X	X	X				X	X					X			X	X		
W_2	θ_2	X								X	X	X												
W_3	θ_3		X	X			X					X	X											
W_4	θ_4				X							X		X			X		X	X			X	
W_5	θ_5			X			X	X	X				X		X	X								

W_1 = Political

W_2 = General Welfare

W_3 = National Security

W_4 = Scientific

W_5 = Technology

The mathematical form of the worth equation is:

$$W = W_1 + W_2 + W_3 + W_4 + W_5$$

where

$$W_1 = \theta_1 \, [a_{5,i} \, Y_5 + a_{6,i} \, Y_6 + a_{7,1} \, Y_7 + a_{11,i} \, Y_{11} + a_{12,1} \, Y_{12} +$$

$$a_{17,1} \, Y_{17} + a_{20,i} \, Y_{20} + a_{21,i} \, Y_{21}]$$

$$W_2 = \theta_2 \, [a_{1,2} \, Y_1 + a_{9,2} \, Y_9 + a_{10,2} \, Y_{10} + a_{11,2} \, Y_{11}]$$

$$W_3 = \theta_3 \, [a_{2,3} \, Y_2 + a_{3,3} \, Y_3 + a_{6,3} \, Y_6 + a_{11,3} \, Y_{11} + a_{12,3} \, Y_{12}]$$

$$W_4 = \theta_4 \, [a_{4,4} \, Y_4 + a_{11,4} \, Y_{11} + a_{13,4} \cdot Y_{13} + a_{16,4} \cdot Y_{16} +$$

$$a_{18,4} \cdot Y_{18} + a_{19,4} \, Y_{19} + a_{22,4} \cdot Y_{22}]$$

$$W_5 = \theta_5 \, [a_{3,5} \, Y_3 + a_{6,5} \, Y_6 + a_{7,5} \cdot Y_7 + a_{8,5} \cdot Y_8 +$$

$$a_{12,5} \cdot Y_{12} + a_{14,5} \, Y_{14} + a_{15,5} \, Y_{15}]$$

θ_i and $a_{j,i}$ are weight factors which are arrived by group judgment (see also Chapter III). Y_i represents individual yield functions which, in this approach, are linear relationships between yield and worth. In each case the Y function is chosen in such a way that the maximum possible yield is identical with the yield of the largest program alternative under consideration.

A typical example for the weight distribution among the individual yield indices is given in Table VII-3. It was obtained by summing all individual θ_i and $a_{i,j}$, and represents an upper limit of the influence each individual yield index can have. In an actual program worth calculation, these terms are multiplied by the selected yield functions Y_i resulting in <u>less</u> than the maximum worth increment in most cases.

TABLE VII-3. RANKED YIELD LIST (APPROACH A)

RANK	YIELD PARAMETER	MAXIMUM WEIGHT (%)
1.	MASS IN EARTH ORBIT	12.25
2.	MAN-YEARS IN EARTH ORBIT	12.25
3.	TOTAL FUNDING	10.5
4.	GLOBAL TRANSPORT CAPABILITY	7.75
5.	NUMBER OF SATELLITES LAUNCHED	7.0
6.	NUMBER MAN-TRIPS TO ORBIT	6.25
7.	NUMBER OF SPACE PROBES	5.0
8.	TOTAL EQUIVALENT MASS IN EARTH ORBIT	4.75
9.	YEAR OF FIRST PLANETARY LANDING	4.0
10.	YEAR OF AVAILABILITY OF LARGEST CARRIER VEHICLE	4.0
11.	NUMBER OF PLANETARY MAN-YEARS	4.0
12.	NUMBER OF SCIENTIFIC LBS ON THE PLANETS	3.0
13.	NUMBER OF LUNAR MAN-YEARS	3.0
14.	DOC $/MAN-TRIP TO ORBIT	2.5
15.	R&D (TOTAL) FUNDING	2.25
16.	YEAR OF FIRST FLYBY	2.0
17.	NUMBER OF SPACE PROBES BEFORE 1975	2.0
18.	NUMBER OF LUNAR MAN-YEARS BEFORE 1975	2.0
19.	SCIENTIFIC LBS TO MOON	2.0
20.	DOC $/LB IN ORBIT	1.5
21.	AVAILABILITY OF NUCLEAR VEHICLE	1.0
22.	SCIENTIFIC LBS TO EARTH ORBIT	1.0
	TOTAL	100.0

The weight factors listed in Table VII-3 have been used in some pilot evaluations to test the validity of this approach.

D. APPROACH B

This is a more sophisticated approach than A. It is machine operated, allows up to 25 program objectives, up to 20 yield parameters, and introduces non-linear relationships between yield and worth. It allows calculation of worth values on an annual basis and makes adjustments with respect to time of accomplishment of individual space flight goals. A "learning curve" function is used to devaluate the yield with increasing yield values, which in effect reduces the worth of a certain yield with time. In this approach sampled opinions play a maximum role in establishing the required weight factors. "Worth" is defined here as an abritrary unit and is not limited by a maximum value.

In brief, Approach B consisted of setting up a correlation matrix between measurable yields and the program objectives. For purposes of development of the method, a list of five major program objectives was used. The matrix which contained 16 yield indices is shown in Table VII-4. It contains 5 objectives and 15 yield parameters, 9 of which are tied to a target date. The judges, whose opinions were solicited, were requested to fill in the matrix with numbers, each of which represented (in their opinion) in a relative way, the degree of a particular yield satisfied a particular objective.

TABLE VII-4. OBJECTIVE - YIELD CORRELATION MATRIX (APPROACH B)

KEY YEARS →	1972	1974	1975	1975	1976	1976	1979	1980	1987						
YIELDS → / OBJECTIVES ↓	KILOPOUNDS USEFUL PAYLOAD IN EARTH ORBIT	SCIENTIFIC MAN-WEEKS IN EARTH ORBIT	MISSION SUPPORT MAN-WEEKS IN EARTH ORBIT	KILOPOUNDS USEFUL PAYLOAD TO THE MOON	MAN-WEEKS ON THE MOON	KILOPOUNDS OF USEFUL PAYLOAD IN CIS-PLANETARY SPACE	KILOPOUNDS OF USEFUL PAYLOAD ON THE PLANETS	MAN-YEARS IN VICINITY OF PLANETS	MAN-WEEKS ON PLANETS	DEVELOPMENT OF REUSABLE ORBITAL TRANSPORT	DEVELOPMENT OF POST-SATURN	DEVELOPMENT OF GLOBAL RANGE ORBITAL TRANSPORT	DEVELOPMENT OF SOLID CORE NUCLEAR FERRY	DEVELOPMENT OF NUCLEAR PULSE FERRY	DEVELOPMENT OF SPACECRAFT SYSTEMS
POLITICS, PRESTIGE	37.5	63	35.4	66.1	97.8	37.5	88.5	105.2	147.2	48.4	60	55	51.8	-9.8	33.3
NATIONAL SECURITY	154.4	128.7	184.1	51.4	79.6	5.6	1.1	5.5	11	115.4	43.2	52.6	26.3	59.6	51.4
GENERAL WELFARE	145.3	161.4	93.2	44.1	55.5	45.2	36.8	44.5	44.5	82.8	45.7	70.3	45.7	26.6	58.9
SCIENCE AND TECHNOLOGY	54.6	83	31.3	47.1	71.9	70.4	62.8	104	169.1	45.8	47.8	53	42.8	39.9	61.5
TRANSPORTATION SYSTEMS	33.5	32	45.2	25.7	29.1	34.9	34.9	31.6	37.7	231.5	97.6	213.3	68.2	50.1	34.6

Another feature of this approach is the use of a learning curve. As we have more and more activities and experience in a particular space environment, we will learn more about that environment and what its potentialities are and the value of continuing that activity will be somewhat decreased. To express this devaluation of yield numerically, a learning curve function was chosen. The nature of this function is that the second unit of yield is worth a given fraction, say 90 percent, of the first unit of yield, then the fourth unit is again worth only 90 percent of the second, the eighth unit only 90 percent of the fourth, etc. In the worth analysis described here, learning curve slopes were selectable parameters and a different learning curve slope could be selected for each yield item if desired. If it were preferred not to use the learning curve slope at all, a slope of zero could be used.

The following nomenclature and symbols are used in exposition of the mathematical methodology used for the Approach B worth analysis:

NOMENCLATURE

$[V_c]$	Correlation matrix (Table VII-4)
v	Elements of $[V_c]$
$[W_o]$	Matrix of program objective weighting factors
w	Elements of $[W_o]$
$[W_o^p]$	Modified version of $[W_o]$; politically oriented (see text)
$[W']$; $[W_s]$	Intermediate matrices used in computing worth matrix
$[W'^p]$; $[W_s^p]$	Politically oriented version of $[W']$ and $[W_s]$ (see text)
$[Y]$	Yield matrix
$[Y']$	Adjusted yield matrix
y	Elements of yield matrix
y'	Elements of adjusted yield matrix
[ ]	Indicates a matrix
[ ] [ ]	Indicates matrix multiplication

GREEK SYMBOLS

λ	Learning curve slope
$[\Omega]$	Worth matrix
ω	Elements of $[\Omega]$

SUBSCRIPTS

i	Index of objectives
j	Index of yields
k	General index
l	Index of program years

The model will accept up to 25 objectives, 20 yield items, and a 25-year program. Some increase in capacity could be obtained with very little effort.

The following are needed as inputs:

1. Number of objectives and yield items; length of program, initial year.

2. Name of each objective item; whether it is political in nature; its weighting factor.

3. Name of each yield item; year before which it should be first accomplished to get political and prestige value; learning curve slope.

4. Correlation matrix.

5. Yield matrix.

6. Cost matrix.

7. Title of run.

$$\text{The yield matrix is of the form, } [Y] = \begin{array}{c} \longleftarrow \text{yields} \longrightarrow \\ \begin{bmatrix} y_{11} & y_{12} \cdots\cdots\cdots & y_{1j} \\ y_{21} \cdots\cdots\cdots & & \\ \cdots\cdots\cdots & & \\ y_{l1} \cdots\cdots\cdots & & y_{lj} \end{bmatrix} \end{array} \updownarrow \text{years}$$

where y_{11} is the yield in category "1" for year 1 (the first year in the program); j ranges from 1 to the number of yield items and l ranges from 1 to the number of years in the program.

The learning curve is defined as follows: the adjusted value of the kth unit of field, y'_k, is equal to the unadjusted value diminished by the ratio $(\Sigma_y)^{1+\lambda}/\Sigma_y$ where λ is the learning curve slope, normally negative. The adjusted value of all yield up to and including the kth unit is

$$Y'_k = \int_0^{y_k} y^{\lambda} dy = \frac{y_k^{1+\lambda}}{1+\lambda} .$$

The adjusted value of the yield delivered in a given year is, therefore,

$$y'_j \quad \frac{y_{lj}^{1+\lambda} - y_{l-1,j}^{1+\lambda}}{1+\lambda} .$$

This relation is used to construct an adjusted yield matrix, $[Y']$. The total yield in a given category over the program is, of course

$$y_s = \sum_l y_{lj} ,$$

$$y'_s = \sum_l y'_{lj} .$$

Both unadjusted and adjusted values are of interest.

$$[W_o] = \begin{array}{c} \longleftarrow \text{objectives} \longrightarrow \\ [w_1\ w_2 \cdots\cdots\cdots w_i] \end{array}$$

where i ranges from 1 to the number of objectives. The correlation matrix assigning certain weight factors to yield indices and individual objectives if of the form,

$$
\begin{array}{cc}
\longleftarrow \text{yields} \longrightarrow & \\
[V_c] = \begin{bmatrix} V_{11} & V_{12} & \cdots\cdots\cdots & V_{1j} \\ V_{21} & \cdots & \cdots\cdots\cdots & \cdots \\ \cdots & \cdots & \cdots\cdots\cdots & \cdots \\ V_{i1} & \cdots & \cdots\cdots\cdots & V_{ij} \end{bmatrix} & \updownarrow \text{objectives}
\end{array}
$$

It is assumed that the worth delivered in a given year for a given yield category and a given objective can be computed by multiplying the adjusted yield by the weighting factor for that objective, and then by the appropriate value in the correlation matrix. In other words, if we wish to know the worth for yield category 3 in the fourth year for objective 2, we have

$$w_{2,3,4}' = y_{43}' \; v_{23} \; w_2 \quad .$$

Summing over objectives gives the worth for that year and that yield item. In matrix form:

Step One: $[W'] = [W_o] \, [V_c]$

where the elements of $[W']$ are w_{ij}'

A new row matrix, $[W_s]$, is generated by $w_j'' = \sum_i w_{ij}'$

The worth matrix is then formed by

$$[\Omega] = [W_s] \, [Y'] \, ,$$

where elements of $[\Omega]$ are ω_{1j} .

A modification to the above basic model was made to give consideration to time of achievement of milestones (first yield in each yield category). First, a special matrix $[w_o^p]$ was constructed in which the elements W_i were zero if the corresponding objective was not political. For example, if only the first objective was political, $[W_o^p]$ would be $[W_1\ 0\ 0 \ldots\ 0]$. Equations (11) and (12) were then used with $[W_o^p]$ in place of $[W_o]$ to form $[W'^2]$ and $[W_s^p]$. This was repeated with a special matrix $[W_o^o]$ for which the elements w_i were zero if the corresponding objective was political; resulting in $[W'^0]$ and $[W_s^o]$.

Next, the adjusted yield matrix $[Y']$ was modified according to the following rule, to form $[Y'^p]$:

1. If first yield was achieved before or during the key year entered in item (3) of the inputs, this yield was multiplied by 10.

2. For each year thereafter, or after the key year, if the first yield was not achieved by the key year, yield was divided by 2.

3. If no key was entered, yields in that category were not changed.

The following matrix of 3 yield categories is given as an example:

Category 1 (Key Year 1970)	Category 2 (Key Year 1972)	Category 3 (No Key Year)	Program Year
0	0	0	1967
10 (y_{21})	0	0	1968
$\frac{1}{2} y_{31}$	0	0	1970
$\frac{1}{4} y_{41}$	0	y_{43}	1971
$\frac{1}{8} y_{51}$	0	y_{53}	1972
$\frac{1}{16} y_{61}$	$\frac{0}{2}$	y_{63}	1973
$\frac{1}{32} y_{71}$	$\frac{1}{4} y_{72}$	y_{73}	1974
$\frac{1}{64} y_{81}$	$\frac{1}{8} y_{82}$	y_{83}	1975
$\frac{1}{128} y_{91}$	$\frac{1}{16} y_{92}$	y_{93}	1976

Two worth matrices were then formed:

$$[\Omega]^p = [W_s^p] [Y'^p] \quad \text{and} \quad [\Omega^\circ] = [W_s^o] [Y']$$

Note that if no key years are entered for any of the yield categories, the two versions of the model are identical.

Several observations may be made regarding the weak features and limitations of this worth model. Regarding the validity of the basic inputs to the matrix determining the weight factors, it is important to have a rather large and knowledgeable sample of judges. This will reduce the risk of arriving at a non-representative distribution of the weight factors between subprograms.

One of the principal difficulties in worth analysis is the question of whether or not the individual judge, even one who has spent some time thinking about it, can properly weigh the relative value of planetary versus lunar versus orbital activity 20 years from now. They are asked to do this in formulating the correlation matrix. This judgment must actually span the entire time period of the program and, therefore, tends to be very difficult. One may also question the method of manipulating the inputs because other methods could certainly be chosen, and the one that was used was the result of one man's opinion.

This model is very weak in the area of properly assessing the political worth of the various yield items. The political worth of achieving a milestone first, such as a planetary landing, should be approximately commensurate with the weighting factor given politics and prestige objectives, and should not particularly be a function of the amount of yield achieved in establishing the milestone. Political worth can be readily handled in the type of WAM (Approach C) that uses specific worth-estimating equations, because in that approach the political worth assigned to milestone achievement can be readily adjusted by suitably modifying the parameters in the worth estimating equations. The Worth Estimating Relationships model may be characterized as relying on the judgment of one or a very few individuals who have spent a considerable amount of time analyzing the problem, whereas the matrix model described here may be characterized as relying on the average judgment of a large number of people who have spent much less time thinking about the details of the problem.

E. APPROACH C

This approach combines some of the features of Approaches A and B into a more sophisticated treatment. A total of 20 objectives are specified and up to 60 yield indices can be used to construct one worth estimating relationship for each of the specified objectives. The number of terms in each equation was selected to be proportional to the weight assigned to each objective. Two terms (representing different yield indices) have then been selected for each percentage point of weight, thus resulting in about 200 terms (out of 20 x 60 = 1200 possible terms) for all 20 worth estimating relationships. This fairly large number will result in a relative insensitivity with respect to the weight assigned to each term. For this reason, it appears to be permissible for the early testing of this model to give equal weight to each term. However, the model does allow for changes to these weights because the application of the model to actual problems will result in more insight, which could be used to adjust the weight factors, if necessary. The two major value judgments are: (1) to assign weights to the objective list; and (2) to select those yield parameters that seem to be most representative among the available yield indices with respect to the individual objective. Both of these judgments are reasonably easy to make, and are probably the least objectionable of those possible within the framework of such a complex problem as this. The resulting computation matrix is shown in Table VII-5.

TABLE VII-5. COMPUTATION MATRIX (APPROACH C)

		G_1						G_2					G_l	
OBJ. $[O_i]$	OBJ. WT. $[\theta_i]$	Y_1	Y_2	Y_3		Y_k	$\sum_j^k$	Y_{11}		Y_j			Y_{60}	
O_1	θ_1	$a_{11}q_{11}$					$\sum_{j=1}^{10} a_{1j}q_{1j}$							$\sum_j a_{ij}q_{ij}$
O_2	θ_2													
O_3	θ_3													
|	|													
|	|													
|	|													
O_i	θ_i									$a_{ij}q_{ij}$				
|	|													
|	|													
O_{20}	θ_{20}												$a_{20,60}q_{20,60}$	
	$\sum_i \theta_i = 100$	$\sum_{i=1}^{20} a_{i1}q_{i1}$					$\sum_{i=1}^{20}\sum_{j=1}^{k} a_{ij}q_{ij}$							$\sum_i\sum_j a_{ij}q_{ij}$

The "Program Yield" used in this model is defined as the sum of all the things produced by a space program. This might consist of the scientific data returned, number of passengers transported between two destinations in space, gain in national prestige achieved by reaching a space goal at a specified time, increase in foreign trade by advancing the entire technology to a level of higher performance and efficiency, and many other things that could be identified as products of a space program. It is assumed now that all of these products are related in one way or another to the number of people and amount of mass moved between individual places in space, and also to the time when these things are accomplished. With this simplification, a number of measurements of yield can be defined and these are grouped into three classes:

1. Transportation Quantity (mass or people),
2. Transportation Effectiveness ($/unit mass or people),
3. Time of Accomplishment of Individual Goals.

These measurements of yield can also be grouped according to activity areas, such as:

1. Total Program (including sub-orbital operations),
2. Earth-Orbital Subprogram,
3. Earth-Lunar Subprogram,
4. Earth-Planetary Subprogram.

Such a list of representative measurements of yield now has to be defined for post-Apollo space programs; it must not be too sophisticated to be manageable, but descriptive enough to produce the desired results with adequate accuracy. Table VII-6 is such a typical list of 44 measurements of yield, which have been identified to date. It should be kept in mind that yields relate directly to the number and types of successful space vehicles launched, which in turn produce the basic program cost.

After selecting the characteristics of the yield terms to be used to construct the "Worth Estimating Relationships" (WER's), the number of terms to have in each of the 20 worth estimating equations was determined. It was concluded that an average of 10 terms per equation is a good compromise between complexity and accuracy. The distribution of these terms over the 20 equations,

TABLE VII-6. MEASUREMENTS OF YIELD (APPROACH C)

TOTAL PROGRAM

1. TOTAL SPACE PROGRAM EXPENDITURE
2. TOTAL NUMBER OF UNMANNED FLIGHTS
3. TOTAL NUMBER OF MANNED FLIGHTS
4. TOTAL EARTH ORBITAL EQUIVALENT MASS DELIVERED
5. TOTAL CAPACITY FOR EQUIVALENT LUNAR MAN-YEARS
6. AVAILABILITY AND SIZE OF LARGEST LAUNCH VEHICLE
7. AVAILABILITY OF FIRST NUCLEAR PROPULSION FLIGHT SYSTEM

EARTH ORBITAL SUBPROGRAM

TRANSPORTATION AND SCIENTIFIC YIELDS:
8. NUMBER OF INSTRUMENTED SATELLITES LAUNCHED SUCCESSFUL
9. USEFUL PAYLOAD MASS DELIVERED
10. NUMBER OF SUCCESSFUL MANNED ROUND TRIPS
11. MAN-YEARS AVAILABLE, LOW ORBIT EQUIVALENT
12. NUMBER OF SUB-ORBITAL (GLOBAL) MAN-TRIPS

EFFICIENCY YIELD PARAMETERS:
13. DOC CARGO TO ORBIT
14. DOC $/MAN TO ORBIT
15. TOC $/MAN TO ORBIT

MILESTONES:
16. FIRST ONE YEAR MANNED FLIGHT
17. FIRST LOW ALTITUDE ORBITAL LAB
18. FIRST SYNCHRONOUS ORBITAL LAB
19. FIRST LARGE ORBITAL STATION
20. FIRST "LOW-G AND -COST" MANNED FLIGHT SYSTEM (ROT)
21. FIRST GLOBAL AND ORBITAL TRANSPORTATION SYSTEM

EARTH-LUNAR SUBPROGRAM

TRANSPORTATION AND SCIENTIFIC YIELDS:
22. TOTAL NUMBER UNMANNED PROBES DELIVERED
23. TOTAL MAN-YEARS AVAILABLE ON LUNAR SURFACE
24. TOTAL NUMBER OF MANNED ROUND TRIPS
25. TOTAL MASS DELIVERED TO LUNAR SURFACE

EFFICIENCY YIELD PARAMETERS:
26. DOC PERSONNEL
27. TOC PERSONNEL

MILESTONES:
28. FIRST ONE YEAR STAY
29. FIRST 10 MAN/1 YEAR BASE
30. FIRST 50 MAN/5 YEAR BASE
31. FIRST LOW "G" TRANSPORTATION SYSTEM

EARTH-PLANETARY SUBPROGRAM

TRANSPORTATION AND SCIENTIFIC YIELDS:
32. TOTAL NUMBER AND MASS OF INTERPLANETARY PROBES DELIVERED
33. TOTAL NUMBER AND MASS OF PLANETARY PROBES DELIVERED
34. TOTAL NUMBER OF ON-PLANET MAN-YEARS
35. TOTAL MASS DELIVERED TO PLANETARY SURFACES

EFFICIENCY YIELD PARAMETERS:
36. DOC PERSONNEL TO MARS SURFACE
37. TOC PERSONNEL TO MARS SURFACE

MILESTONES:
38. FIRST MARS SURFACE PROBE
39. FIRST SOLAR SYSTEM ESCAPE
40. FIRST MANNED PLANETARY FLYBY
41. FIRST MANNED PLANETARY ORBITER
42. FIRST MANNED PLANETARY LANDER
43. FIRST 10 MAN-YEARS ON MARS
44. FIRST LOW "G" PLANETARY TRANSPORTATION SYSTEM

however, is regulated by the weight which that equation received in the weighted objective list to obtain a uniform distribution. Therefore, each point of weight is represented roughly by two terms in the corresponding worth estimating relationship, thus requiring at least 200 (2 x 100) terms.

These 200 terms were selected from a possible total of 1200 (60 x 20). A choice was made on a case-to-case basis and this choice is indicated in Table VII-7. This is a checklist to determine the yield measurements that are best suited to indicate the degree to which an objective will be reached (worth). An additional degree of freedom is offered by assigning a weight factor to each term in each equation, thus shifting the weight from one yield parameter to another. This is particularly of interest for a sensitivity analysis. In a situation where little experience is available in the manipulation of a solution to a problem, it is advisable to begin with the "naive" approach, in which each of the terms receive equal weight. It should be noted that each term in the WER's representing a milestone will be multiplied by the probability of mission success (cumulative) for the time period under consideration. If this is applied to the problem, the following weight distributions are obtained by multiplying the objective weight

TABLE VII-7. YIELD PARAMETERS USED FOR WORTH ESTIMATING RELATIONSHIPS (APPROACH C)

OBJECTIVE	TOTAL PROGRAM							EARTH-ORBITAL SUBPROGRAM														EARTH-LUNAR SUBPROGRAM										EARTH-PLANETARY SUBPROGRAM												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
1	X	X	X	X	X									X		X	X			X	X					X		X			X					X						X		X
2	X			X	X			X	X	X	X	X	X	X			X	X	X	X	X																							
3								X			X											X	X									X	X	X				X	X	X	X		X	
4	X	X	X	X	X	X				X							X	X	X	X	X																							
5	X									X	X						X		X	X			X	X								X						X				X		
6		X	X											X					X	X	X		X								X												X	X
7	X		X		X												X		X	X	X										X									X		X		X
8	X	X				X				X								X			X		X											X									X	X
9	X			X		X		X		X			X	X			X		X	X				X																				
10								X	X	X	X	X				X	X	X	X	X	X																							
11	X							X	X		X							X	X			X	X									X	X											
12	X	X	X	X		X														X	X		X											X										
13			X											X	X					X	X					X	X				X					X	X							X
14	X	X	X	X		X	X													X			X											X										
15	X		X			X						X		X	X					X	X																							
16	X		X		X							X		X	X					X	X																							
17	X			X				X													X		X											X										
18	X		X											X	X					X	X																							
19		X											X									X										X						X	X					
20																							X		X									X	X	X								X

factors, times the weight factors of the individual terms determining the worth. With respect to classes of yield parameters, the distributions are:

1. Eighteen volume parameters have a weight of 47 percent.

2. Seven cost effectiveness parameters have a weight of 11 percent.

3. Nineteen milestone parameters have a weight of 42 percent.

With respect to program activity, the distributions are:

1. Total program yield indices receive up to 25 percent of the weight.

2. Earth-orbital subprogram receives up to 44 percent of the weight.

3. Earth-lunar subprogram receives up to 14 percent of the weight.

4. Earth-planetary subprogram receives up to 17 percent of the weight.

It does not seem unreasonable to give the Earth-orbital subprogram a greater weight than the combined lunar and planetary subprograms, because, as indicated before, the maximum benefits derived from the space program should be in the area of economical benefits. These benefits obviously will come from near-Earth space applications.

TABLE VII-8. RANKED YIELD MEASUREMENTS (APPROACH C)

RANK		WT. (%)
1.	TOTAL SPACE PROGRAM EXPENDITURE	6.95
2.	FIRST LOW "G" AND LOW COST MANNED SPACE VEHICLE	6.84
3.	FIRST GLOBAL AND ORBITAL TRANSPORTATION SYSTEM	6.34
4.	TOTAL NUMBER OF MANNED FLIGHTS	5.04
5.	TOTAL MAN-YEARS AVAILABLE ON LUNAR SURFACE	4.27
6.	FIRST LARGE ORBITAL SPACE STATION	3.99
7.	DOC $/MAN-TRIP TO EARTH ORBIT	3.92
8.	TOTAL EARTH ORPITAL EQUIVALENT MASS DELIVERED	3.62
9.	FIRST LOW ALTITUDE ORBITAL LABORATORY	3.50
10.	TOTAL NUMBER OF UNMANNED FLIGHTS	3.37
11.	NUMBER OF INSTRUMENTED SATELLITES LAUNCHED SUCCESSFULLY	3.04
12.	NUMBER OF SUCCESSFUL MANNED ORBITAL ROUNDTRIPS	2.98
13.	AVAILABILITY AND SIZE OF LARGEST LAUNCH VEHICLE	2.93
14.	TOTAL NUMBER OF ON-PLANET MAN-YEARS	2.78
15.	FIRST PLANETARY LOW "G" TRANSPORTATION SYSTEM	2.71
16.	MAN-YEARS AVAILABLE IN LOW EARTH ORBIT (EQUIVALENT)	2.53
17.	TOTAL CAPACITY FOR EQUIVALENT LUNAR MAN-YEARS	2.53
18.	FIRST SYNCHRONOUS ORBITAL EARTH LABORATORY	2.51
19.	FIRST LUNAR LOW "G" TRANSPORTATION SYSTEM	2.37
20.	NUMBER OF MANNED GLOBAL ROUND TRIPS	2.00
21.	TOTAL NUMBER AND MASS OF INTERPLANETARY PROBES DELIVERED	1.95
22.	TOC $/MAN TO ORBIT	1.89
23.	USEFUL (UNMANNED) PAYLOAD MASS DELIVERED INTO EARTH ORBIT	1.54
24.	FIRST MANNED PLANETARY LANDING	1.48
25.	DOC CARGO TO EARTH ORBIT	1.47
26.	TOTAL NUMBER OF UNMANNED LUNAR PROBES DELIVERED	1.46
27.	FIRST 10 MAN-YEARS ON MARS	1.46
28.	FIRST MARS SURFACE PROBE	1.43
29.	DOC FOR ONE MANNED LUNAR ROUND-TRIP	1.43
30.	DOC FOR ONE MANNED ROUND TRIP TO MARS	1.28
31.	TOTAL NUMBER AND MASS OF UNMANNED PLANETARY PROBES DELIVERED	1.03
32.	FIRST ORBITAL FLIGHT WITH ONE-YEAR DURATION	1.00
33.	TOTAL NUMBER OF MAN-ROUND-TRIPS TO THE MOON	0.99
34.	FIRST ONE-YEAR MANNED LUNAR STATION	0.99
35.	FIRST MANNED PLANETARY FLYBY	0.98
36.	AVAILABILITY OF FIRST NUCLEAR FLIGHT SYSTEM	0.97
37.	FIRST 50-MAN/5-YEAR LUNAR BASE	0.95
38.	FIRST SOLAR SYSTEM ESCAPE	0.94
39.	FIRST MANNED PLANETARY ORBITER	0.51
40.	FIRST 10-MAN/ONE-YEAR LUNAR BASE	0.49
41.	TOC PERSONNEL TO MOON AND BACK	0.44
42.	TOC PERSONNEL TO MARS AND BACK	0.44
43.	TOTAL MASS DELIVERED TO PLANETARY SURFACES	0.33
44.	TOTAL MASS DELIVERED TO LUNAR SURFACE	0.33
	TOTAL	100.00

Table VII-8 gives the presently used maximum weights of each yield index. These result from the assumptions used for the weights of the objectives and the number of terms chosen for the case where each term selected has an equal weight. This ranked yield index list is a first step in testing of the validity of the model.

F. APPROACH C COMPUTER MODEL

The objective of the computer model is to automate the computation procedure of the WAM (Approach C) so a number of alternative space programs can be evaluated quickly with a minimum of effort by the analyst. The following paragraphs list the model inputs and outputs, and describe the computation procedure:

1. Inputs

The following is a list of inputs required by the model to evaluate one alternate space program:

a. Program yields that describe the accomplishments of the program (with the 44 yield parameters there are 88 additional inputs needed to define the value of the worth function).

b. The weight that each objective contributes to total program worth (there are 20 of these values).

c. A function that relates the worth of each yield to the program objectives (there are at present 3 with space for 3 more).

d. A weighting function that relates each yield used to evaluate a specified objective to the total objective weight (this could vary from 1 to 200 inputs according to the scheme used).

e. In addition to the above, approximately 10 inputs are required to instruct the computer as to which computation and output option are required for each run.

The above list of inputs results in approximately 360 inputs required to make the first run on the computer. If additional runs are to be made, the 360 inputs will be reduced to 44 straight program yield inputs for each additional run. This allows a minimum of effort in evaluating multiple space programs.

2. Computation Procedure

The procedure, programmed for the IBM 7094 computer, is rather simple in concept. The computation matrix, shown in Table VII-5, indicates the magnitude of the task. The matrix consists of 20 objectives designated by "Θi" and up to 60 yields relationships designated by "Yj." The "Y's" are partitioned into four groups designated by "Gi." The objective weights (Θi) are inputs to the model. The basic task of the model is to compute the non-zero elements of the 20 x 60 matrix. These elements can then be summed to determine objective worth, group objective worth, and total program worth; these outputs will be discussed later.

Each non-zero element in the matrix is a product of two terms; the "Aij" term of each element is a function of the program yields and is related to program worth by an exponential function of the form:

$$\exp \frac{(y - b)}{\alpha} \quad \text{or} \quad 1 - \exp \frac{(y - b)}{\alpha}$$

where

y = yield value or milestone date at time of program evaluation

b = translation constant or reference year of yield accomplishment

α = parameter used to vary the slope of the worth function

At present, the above forms are in the functional library of the model. There are provisions for 4 additional functions to be added later if the two present forms are not adequate. The y's, b's and α's are inputs to the model and are required for each yield considered; the last two are chosen by the analyst.

The "q_{ij}" term of each non-zero element is a function of the weight that each yield contributes to the program objectives. At present there are three schemes for computing or inputing the q's, and they are:

a. All yields used for each objective have equal weight.

b. The yields used within each group "Gi" have equal weight where the groups are given a predetermined percentage of the objective weight (Θ).

c. The "q's" are determined externally to the model and are input directly into the model.

The first two schemes are computed within the model with only an instruction card needed to indicate which scheme is to be used. The third method is used when a method of weighting is desired other than the first two. In this case a "q" must be input for each man-zero element.

The model is structured so that any one of the yield functions can be used to compute the worth of each yield for each objective. The analyst has the option of specifying which yield should be used for each objective and which function best relates the worth of this yield to the objective. This option allows complete flexibility in the computation of the "Aij" values. It should be emphasized that additional functions can be added when they are defined. The structure of the model also allows any of the weighting schemes to be used with each run.

The model was developed and is programmed so that all of its major variables and parameters can be changed from run to run. It is also structured so that a minimum of effort is required to make multiple runs. The machine run-time is less than one minute per run. The input time for the first run is about an hour. For each consecutive run, only about 10 minutes are required to make an input.

The model also has a subroutine to determine the delta worth that is obtained when the space program is considered in time intervals, i.e., to determine how worth is cumulated as a function of time. The subroutine determines the delta increment of worth that is obtained by increasing the point in time when the yields are calculated with the first yield calculation being the base. This capability allows the worth of the space program to be determined for each year or group of years.

3. Outputs

The outputs of the model are:

a. The worth of each objective (Wi) or ($\sum_j Aij\ qij$ for each "i" objective).

b. Total program worth ($\sum_i Wi$) or ($\sum_i \sum_j Aij\ qij$).

c. Each group worth within each objective ($\sum_{Gj} Aij\ qij$ for each "Gi" group, and for each "i" objective).

d. Total group worth ($\sum_i \sum_{Gj} Aij\ qij$).

e. The total worth contributed by each yield ($\sum_i Aij\ qij$ for each "j" yield).

f. The ΔWi for each i objective.

g. The $\sum_i \Delta Wi$.

h. The Δ's associated with c, d, and e.

This approach seems to offer all the flexibility needed, but it has a basic simplicity that will help to demonstrate its utility.

CHAPTER VIII. PROGRAM EFFECTIVENESS (OUTPUTS)

The remaining task is to make the obtained results visible to management to assist effectively in the decision making process.

There are many indicators that can be used to judge or measure the effectiveness of a program and its degree of desirability. The procedure described in this report produces thousands of figures to choose from for final presentation of results.

A total of five output options are offered to management at the following information levels:

1. National (or international) Program Totals,
2. Agency Program Totals,
3. Total Program Trends versus Time,
4. Subprogram Totals,
5. Subprogram Trends.

There are three categories of information within each of these five output levels, namely:

1. Program Cost,
2. Program Yield,
3. Program Effectiveness

These two groupings result in the output matrix shown in Table VIII-1, which also gives the number of parameters shown as well as the number of charts (formats) to be prepared as part of the evaluation process.

It is considered adequate to have 31 parameters presented on 44 charts available to the Program Administrator in levels 1 through 3, and an additional 45 parameters on 54 charts in levels 4 and 5, as back-up information.

A detailed list of these parameters and charts follows:

NATIONAL PROGRAM COST TOTALS (OUTPUT LEVEL 1)

Note: These cost parameters (CP's) are for the entire time period considered. The CP's are listed on one cost chart (CC-1) with 12 lines by alternative.

CP-1. National program cost.

CP-2. Total government funding, ($) required for national program.

TABLE VIII-1. OUTPUT OPTIONS

NUMBER OF PARAMETERS / NUMBER OF TABLES AND GRAPHS		COST	YIELD	EFFICIENCY	TOTALS
LEVEL	OUTPUT TYPE				
1	NATIONAL PROGRAM TOTALS	8 / 1	6 / 2	4 / 1	17 / 4
2	AGENCY PROGRAM TOTALS	5 / 1	0 / 0	0 / 0	2 / 1
3	TOTAL PROGRAM TRENDS	14 / 14	13 / 26	4 / 4	31 / 44
4	SUB-PROGRAM TOTALS	5 / 5	6 / 9	5 / 5	15 / 33
5	SUB-PROGRAM TRENDS	10 / 28	18 / 76	2 / 6	30 / 98
TOTALS		34 / 49	39 / 113	14 / 16	87 / 178

CP-3. Total government funding (in percent of national program cost, CP-1) required for national program.

CP-4. Total government funding required, distributed over participating agencies (DOD, NASA, Weather Bureau, AEC, National Science Foundation) in percent of CP-2.

CP-5. Non-government funding expected ($) for national program.

CP-6. Average annual government funding ($) required for national program for time period under consideration.

CP-7. Funds ($) required for procurement and operation (direct operating cost) for launch vehicles of the national program.

CP-8. Funds ($) required for R&D, procurement, and operation (total operating cost) for launch vehicles of the national program.

NASA TOTAL PROGRAM FUNDING (OUTPUT LEVEL 2)

Note: These cost parameters (CP's) are shown on one cost chart (CC-2) with 5 lines by alternative.

CP-9. Total NASA funding required for total time period considered by alternative ($).

CP-10. Average annual NASA funding required for total time period considered by alternative.

CP-11. NASA Administrative Operations (AO) funding (in percent of CP-9).

CP-12. NASA R&D funding (in percent of CP-9).

CP-13. NASA Cost of Facilities (C of F) funding (in percent of CP-9).

TOTAL PROGRAM COST TRENDS (OUTPUT LEVEL 3)

Note: If not otherwise specified, annual rates as a function of time by alternative apply. These cost parameters (CP's) are listed on 14 cost charts (CC-3 through CC-16) showing relative standing of the alternatives.

CP-14. Project availability of Federal Government funds for national space program for several projection methods (5 lines) -- CC-3.

CP-15. Total national program government funding required in percent of the Gross National Product (GNP) -- CC-4.

CP-16. Total national program government funding required in percent of the expected Administrative Federal Budget (AFB)-- CC-5.

CP-9. Total NASA funding ($) required -- CC-6.

CP-17. Total NASA funding (in percent of GNP) required -- CC-7.

CP-18. Total NASA funding (in percent of AFB) required -- CC-8.

CP-19. NASA Administrative Operations (AO) funding ($) required -- CC-9.

CP-20. NASA R&D funding ($) required -- CC-10.

CP-21. NASA Construction of Facilities (C of F) funding ($) required -- CC-11.

CP-22. NASA AO funding (in percent of total NASA funding) required -- CC-12.

CP-23. NASA R&D funding (in percent of total NASA funding) required -- CC-13.

CP-24. NASA C of F funding (in percent of total NASA funding) required -- CC-14.

CP-7. Annual funds required (Direct Operating Cost, DOC) for launch vehicles within the national program -- CC-15.

CP-8. Annual funds required (Total Operating Cost, TOC) for launch vehicles within the national program -- CC-16.

SUBPROGRAM COST TOTALS (OUTPUT LEVEL 4)

Note: All cost parameters (CP's) are given for the entire time period under consideration by alternative. These CP's are given in 5 cost charts (CC-17, CC-18, CC-19, CC-12, CC-21), showing the relative overall standing of the alternatives.

CP-25. National program funding distribution ($) by subprogram (suborbital, orbital, lunar, planetary) -- CC-17.

CP-26. National program funding distribution in percent of total funding by subprogram (suborbital, orbital, lunar, planetary) -- CC-18.

CP-27. National program funding distribution in percent of total funding by major cost category (Administrative Operations, Cost of Facilities, Launch Vehicles, Spacecraft, and Mission Payloads) -- CC-19.

CP-28. NASA funding distribution in percent of total NASA funding by subprogram (suborbital, orbital, lunar, planetary) -- CC-12.

CP-29. NASA R&D funding distribution in percent of total NASA R&D funding by major cost category (Launch Vehicles, Spacecraft, and Mission Payloads) -- CC-21.

SUBPROGRAM COST TRENDS (OUTPUT LEVEL 5)

Note: All cost parameters (CP's) are given as a function of time by alternative. These CP's are listed in 28 cost charts (CC-22 through CC-49).

CP-25. Annual national program funding in $ by subprogram -- CC-22 through CC-25.

CP-26. Annual national program funding in percent by subprogram -- CC-26 through CC-29.

CP-30. Annual NASA program funding in $ by subprogram -- CC-30 through CC-33.

CP-28. Annual NASA program funding in percent by subprogram -- CC-34 through CC-37.

CP-31. National program distribution of funds over subprograms within each alternative -- CC-38 through CC-41.

CP-32. NASA program distribution of funds over subprograms within each alternative -- CC-42 through CC-45.

CP-7. National launch vehicle funding in percent of total national funds (direct operating cost only) -- CC-46.

CP-8. National launch vehicle funding in percent of total national funds (total operating cost) -- CC-47.

CP-33. National spacecraft and mission payload funding in percent of total national (direct operating cost only) funds -- CC-48.

CP-34. National spacecraft and mission payload funding in percent of total national (total operating cost) funds -- CC-49.

NATIONAL PROGRAM YIELDS (OUTPUT LEVEL 1*)

Note: These yield parameters (YP's) are given for the entire period considered by alternative. These YP's are given on two yield charts (YC's). YP-1 through YP-5 are given on YC-1 (19 lines by alternative); YP-6 is given on YC-2 (no more than 12 selected milestones by alternative).

YP-1. National program worth (in units of worth) -- YC-1.

YP-2. National program worth (in units of worth), distribution over major benefit groups (general welfare and economy, political, military, scientific and technological) -- YC-1.

YP-3. Total Earth orbit equivalent mass delivered within national program -- YC-1.

YP-4. Total lunar man-year equivalent produced within national program -- YC-1.

YP-5. Total Mars man-year equivalent within national program -- YC-1.

YP-6. Major milestones achieved or not -- YC-2.

TOTAL PROGRAM YIELD TRENDS (OUTPUT LEVEL 3)

Note: These yield parameters (YP's) are given as annual rates as a function of time by alternative. They are listed on 26 yield charts (YC-3 through YC-29) showing the relative standing of the alternatives.

YP-1. Cumulative worth -- YC-3.

YP-7. Annual worth -- YC-4.

YP-3. Cumulative Earth orbit equivalent mass delivered -- YC-5.

*No output level 2.

YP-8. Annual Earth orbit equivalent mass delivered -- YC-6.

YP-9. Number of annual launch attempts -- YC-7.

YP-10. Projected number of successful launches -- YC-8.

YP-11. Projected annual launch reliability -- YC-9.

YP-12. Annual launch rate for unmanned satellites (launch of vehicles) -- YC-10.

YP-13. Annual launch rate for unmanned space probes (lunar and planetary) -- YC-11.

YP-14. Annual launch rate for manned orbital flights -- YC-12.

YP-15. Annual launch rate for manned lunar and planetary flights -- YC-13.

YP-16. Annual launch rate for up to 11 major launch vehicles by type (one chart per type) -- YC-14 through YC-24.

YP-17. Annual manufacturing rate for reusable launch vehicles (one chart per vehicle type) -- YC-25 through YC-29.

SUBPROGRAM YIELD TOTALS (OUTPUT LEVEL 4)

Note: These yield parameters (YP's) are given for the total period under consideration by alternative. The YP's are listed in 9 yield charts (YC-30 through YC-38).

YP-6. Milestones by subprograms -- YC-30 through YC-33.

YP-18. Average annual unmanned payload and cargo mass delivered to destination by subprogram (suborbital, orbital, lunar, and planetary) -- YC-34.

YP-19. Average number of annual manned roundtrips accomplished by subprogram -- YC-35.

YP-20. Average number of mission man-years produced by subprogram with exception of suborbital -- YC-36.

YP-21. Distribution of worth over subprograms (absolute worth points) -- YC-37.

YP-22. As YP-21, but in percent of total worth -- YC-38.

SUBPROGRAM YIELD TRENDS (OUTPUT LEVEL 5)

Note: If not otherwise stated, all yield parameters (YP's) are given as a function of time by alternative. The YP's are given on 76 yield charts (YC-30 through YC-105).

YP-23. Maximum single vehicle one way payload capability (cargo) by subprogram -- YC-30 through YC-32.

YP-24. Maximum single flight passenger capability by subprogram -- YC-33 through YC-35.

YP-25. Actual manning of orbital, lunar, and planetary bases -- YC-36 through YC-38.

YP-26. Actual equivalent Earth orbital mass by subprogram -- YC-39 through YC-42.

YP-27. Actual number of manned round-trips by subprogram -- YC-43 through YC-46.

YP-28. Actual number of manned mission years by subprogram -- YC-47 through YC-49.

YP-3. Cumulative equivalent Earth orbital mass delivered by subprogram -- YC-50 through YC-53.

YP-29. Cumulative number of manned round-trips by subprogram -- YC-54 through YC-57.

YP-30. Cumulative number of mission man-years by subprogram -- YC-58 through YC-60.

YP-31. Projected reliability growth by vehicle (launch vehicles and spacecraft) -- YC-61 through YC-70.

YP-32. Equivalent Earth orbital mass delivered distributed by launch vehicle and alternative (one chart each) -- YC-71 through YC-74.

YP-33. Projected operational life of reusable space vehicles by type -- YC-75 through YC-80.

YP-34. Projected turn-around time of reusable space vehicles by type or stage -- YC-81 through YC-86.

YP-35. Cargo mass required per man-year by subprogram -- YC-87 through YC-89.

YP-36. Projected total mission reliabilities by subprogram -- YC-90 through YC-93.

YP-37. Projected cargo mass returned from destination by subprogram -- YC-94 through YC-97.

YP-38. Personnel returned (projected) from destination by subprogram -- YC-98 through YC-101.

YP-39. Projected personnel loss rates by subprogram -- YC-102 through YC-105.

NATIONAL PROGRAM EFFECTIVENESS TOTALS (OUTPUT LEVEL 1*)

Note: These effectiveness parameters (EP's) are for the entire time period considered, by alternative. The EP's are given on one effectiveness chart (EC-1).

EP-1. National program effectiveness (cost/worth).

EP-2. Average specific direct operating cost for launch vehicles ($/unit mass), based on total Earth orbit equivalent mass delivered.

EP-3. Average specific total operating cost for launch vehicles ($/unit mass), based on total Earth orbit equivalent mass delivered.

EP-4. Average specific program cost ($/lunar man-year), based on total lunar man-year equivalent produced.

*No output level 2.

TOTAL PROGRAM EFFECTIVENESS TRENDS (OUTPUT LEVEL 3)

Note: These effectiveness parameters (EP's) are given as a function of time and by alternative. The EP's are given on four effectiveness charts (EC-2 through EC-5), showing the relative standing of the alternatives.

EP-5. Annual program effectiveness (cost/worth) -- EC-2.

EP-1. Cumulative program effectiveness (cost/worth) -- EC-3.

EP-6. Direct annual operating cost effectiveness for launch vehicles based on Earth orbital mass equivalent mass delivered -- EC-4.

EP-7. Total annual operating cost effectiveness for launch vehicles based on Earth orbital mass equivalent mass delivered -- EC-5.

SUBPROGRAM EFFECTIVENESS TOTALS (OUTPUT LEVEL 4)

Note: These effectiveness parameters (EP's) are for the total period under consideration, by alternative. The EP's are given on five effectiveness charts (EC-6 through EC-10).

EP-8. Average delivery cost per unit mass of cargo by subprogram -- EC-6.

EP-9. Average direct operating cost per man round-trip by subprogram -- EC-7.

EP-10. Average direct operating cost per mission man-year by subprogram -- EC-8.

EP-11. Average orbital mass burden rate by subprogram -- EC-9.

EP-12. Average orbital cost burden rate by subprogram -- EC-10.

SUBPROGRAM EFFECTIVENESS TRENDS (OUTPUT LEVEL 5)

Note: These effectiveness parameters (EP's) are given as a function of time, by alternative. The EP's are given on six effectiveness charts (EC-11 through EC-16).

EP-13. Subprogram cost effectiveness on an annual basis with respect to man-years produced -- EC-11 through EC-13.

EP-14. Subprogram cost effectiveness on an accumulative basis with respect to man-years produced -- EC-14 through EC-16.

Tables VIII-2 through VIII-6 and Figures VIII-1 through VIII-5 illustrate the output formats for output levels 1, 2, and 3 in the areas of cost, yield and program effectiveness. The output formats for levels 4 and 5 are similar in nature and can be prepared with the help of the parameter lists given above.

TABLE VIII-2. COST - OUTPUT LEVEL 1
(CHART CC-1)

PROGRAM PARAMETER	PROGRAM ALTERNATIVE	A	B	C	D
CP-1	NATIONAL PROGRAM COST ($$10^{-9}$)				
CP-2	TOTAL GOVERNMENT FUNDING REQ'D ($$10^{-9}$)				
CP-3	TOTAL GOVERNMENT FUNDING (% OF CP-2)				
CP-4a	NASA FUNDING (% OF CP-2)				
CP-4b	DOD FUNDING (% OF CP-2)				
CP-4c	WB FUNDING (% OF CP-2)				
CP-4d	AEC FUNDING (% OF CP-2)				
CP-4e	NSF FUNDING (% OF CP-2)				
CP-5	NON-GOVERNMENT FUNDING EXPECTED ($$10^{-9}$)				
CP-6	AVERAGE ANNUAL GOVERNMENT FUNDING ($$10^{-9}$)				
CP-7	LAUNCH VEHICLE FUNDING-DOC ($$10^{-9}$)				
CP-8	LAUNCH VEHICLE FUNDING-TOC ($$10^{-9}$)				

TABLE VIII-3. YIELD - OUTPUT LEVEL 1 (CHART YC-1)

PROGRAM PARAMETER / PROGRAM ALTERNATIVE		A	B	C	D
YP-1	NATIONAL PROGRAM WORTH (UNITS OF WORTH)				
YP-2a	POLITICAL BENEFITS (UNITS OF WORTH)				
YP-2b	ECONOMICAL BENEFITS (UNITS OF WORTH)				
YP-2c	MILITARY BENEFITS (UNITS OF WORTH)				
YP-2d	SCIENTIFIC BENEFITS (UNITS OF WORTH)				
YP-2e	TECHNOLOGICAL BENEFITS (UNITS OF WORTH)				
YP-3	EARTH ORBIT EQUIV. MASS DELIV. (1000 Kg)				
YP-4	LUNAR EQUIV. MAN-YEARS PRODUCED				
YP-5	MARS EQUIV. MAN-YEARS PRODUCED				

TABLE VIII-4. YIELD - OUTPUT LEVEL 1 (CHART YC-2)

DATE (YEAR) WHEN MILESTONE IS EXPECTED TO BE ACHIEVED WITH PROBABILITY LARGER THAN 50 PERCENT					
PROGRAM PARAMETER / PROGRAM ALTERNATIVE		A	B	C	D
YP-6a	10 X 10^6 Kg EARTH ORBIT EQUIV. MASS				
YP-6b	1,000 MAN-ROUND-TRIPS TO ORBIT				
YP-6c	100 MAN-YEARS IN EARTH ORBIT				
YP-6d	FIRST REUSABLE AEROSPACE TRANSPORT				
YP-6e	FIRST REUSABLE NUCLEAR SPACE TRANSPORT				
YP-6f	10 MAN-YEARS ON THE MOON				
YP-6g	100 MAN-YEARS ON THE MOON				
YP-6h	10th UNMANNED PLANETARY LANDING				
YP-6i	100 DEEP SPACE PROBES				
YP-6j	1st MANNED PLANETARY FLYBY OR CAPT.				
YP-6k	1st MANNED PLANETARY LANDING				
YP-6l	10 PLANETARY MAN-YEARS				

TABLE VIII-5. PROGRAM EFFECTIVENESS - OUTPUT LEVEL 1 (CHART EC-1)

PROGRAM PARAMETER / PROGRAM ALTERNATIVE		A	B	C	D
EP-1	NATIONAL PROGRAM ($\$10^{-9}$/UNIT WORTH) EFFECTIVENESS (COST/WORTH)				
EP-2	AVERAGE SPECIFIC DOC LAUNCH VEHICLES ($/Kg)				
EP-3	AVERAGE SPECIFIC TOC LAUNCH VEHICLES ($/Kg)				
EP-4	AVERAGE SPECIFIC PROGRAM COST BASED ON EQUIVALENT LUNAR MAN-YEARS ($/MYR)				

TABLE VIII-6. COST - OUTPUT LEVEL 2 (CHART CC-2)

PROGRAM PARAMETER / PROGRAM ALTERNATIVE		A	B	C	D
CP-9	TOTAL NASA FUNDING REQUIRED ($\$10^{-9}$)				
CP-10	AVERAGE ANNUAL NASA FUNDING REQUIRED ($\$10^{-9}$)				
CP-11	NASA ADMIN. OPER. FUNDING REQUIRED (% OF CP-9)				
CP-12	NASA R&D FUNDING REQUIRED (% OF CP-9)				
CP-13	NASA C OF F FUNDING REQUIRED (% OF CP-9)				

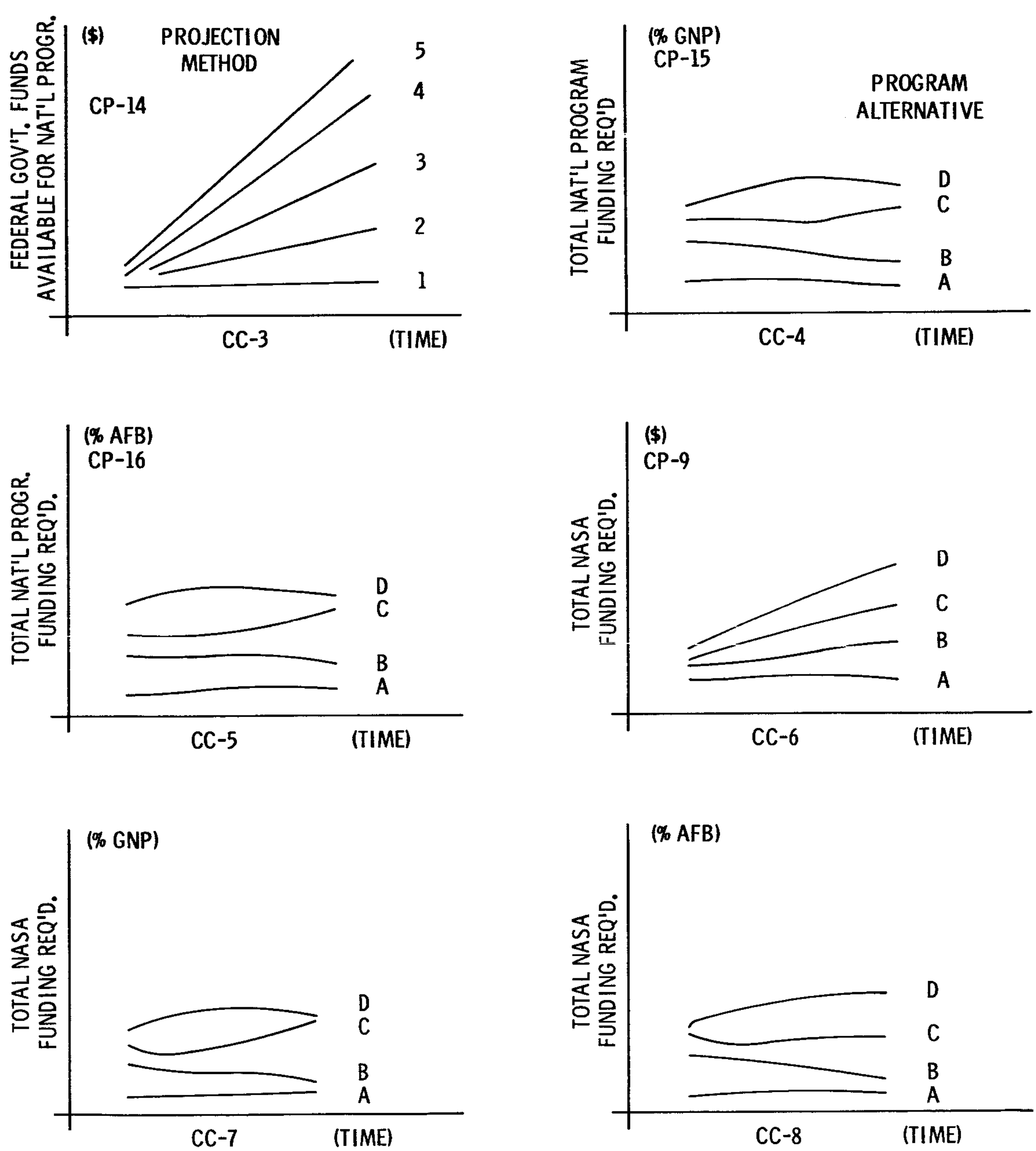

FIGURE VIII-1. COST OUTPUT LEVEL 3

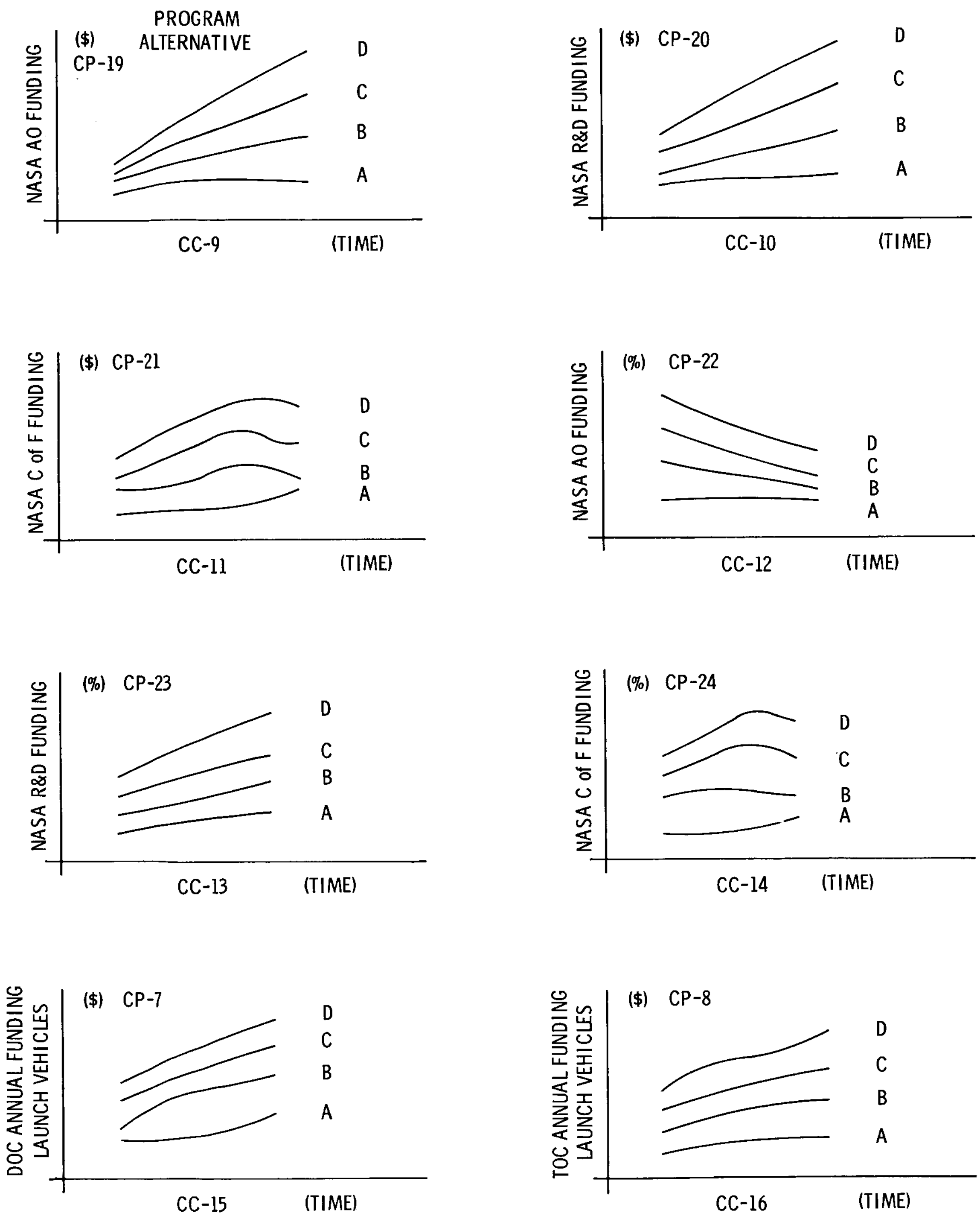

FIGURE III-2. COST OUTPUT LEVEL 3 (Cont'd)

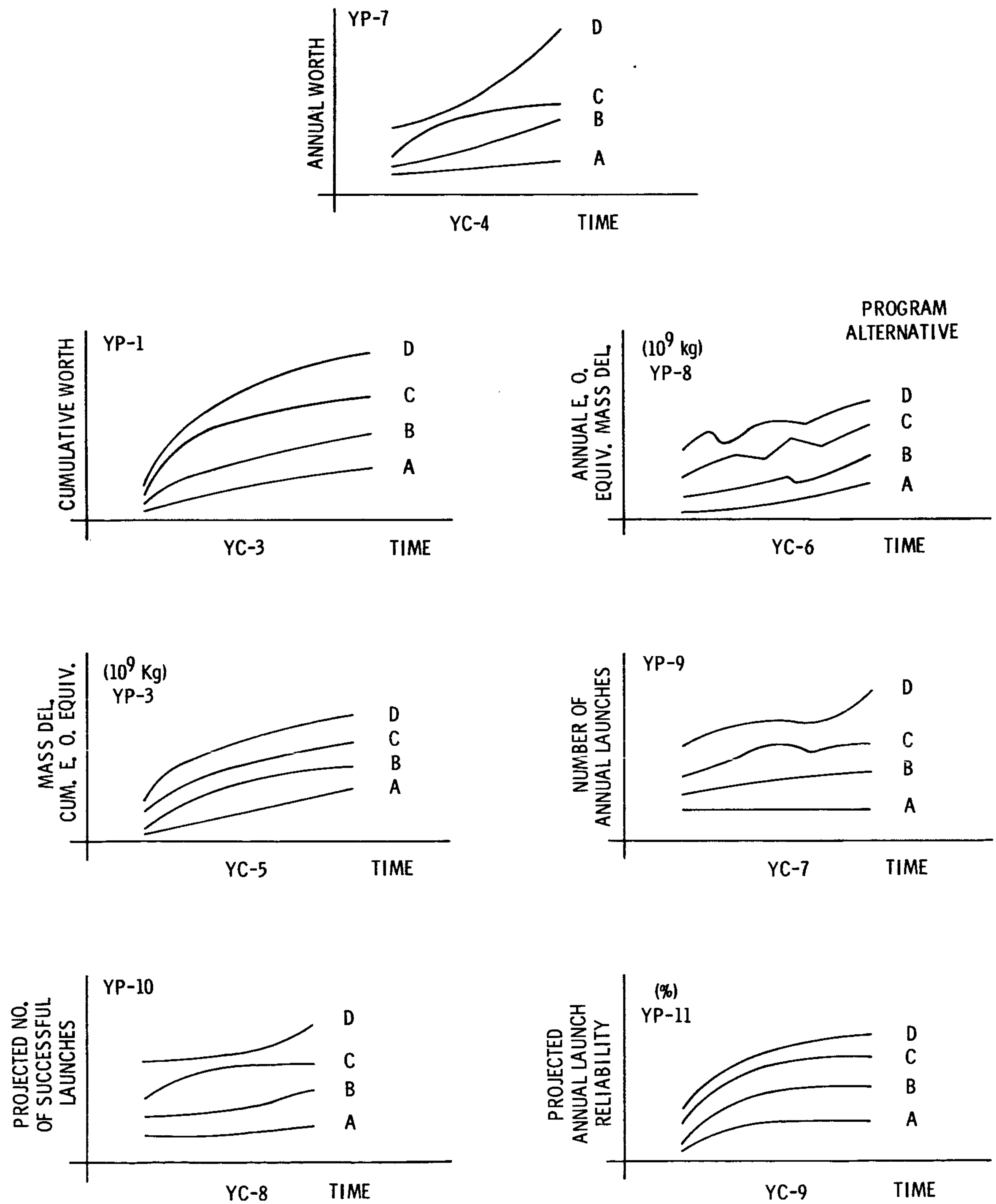

FIGURE VIII-3. YIELD OUTPUT LEVEL 3

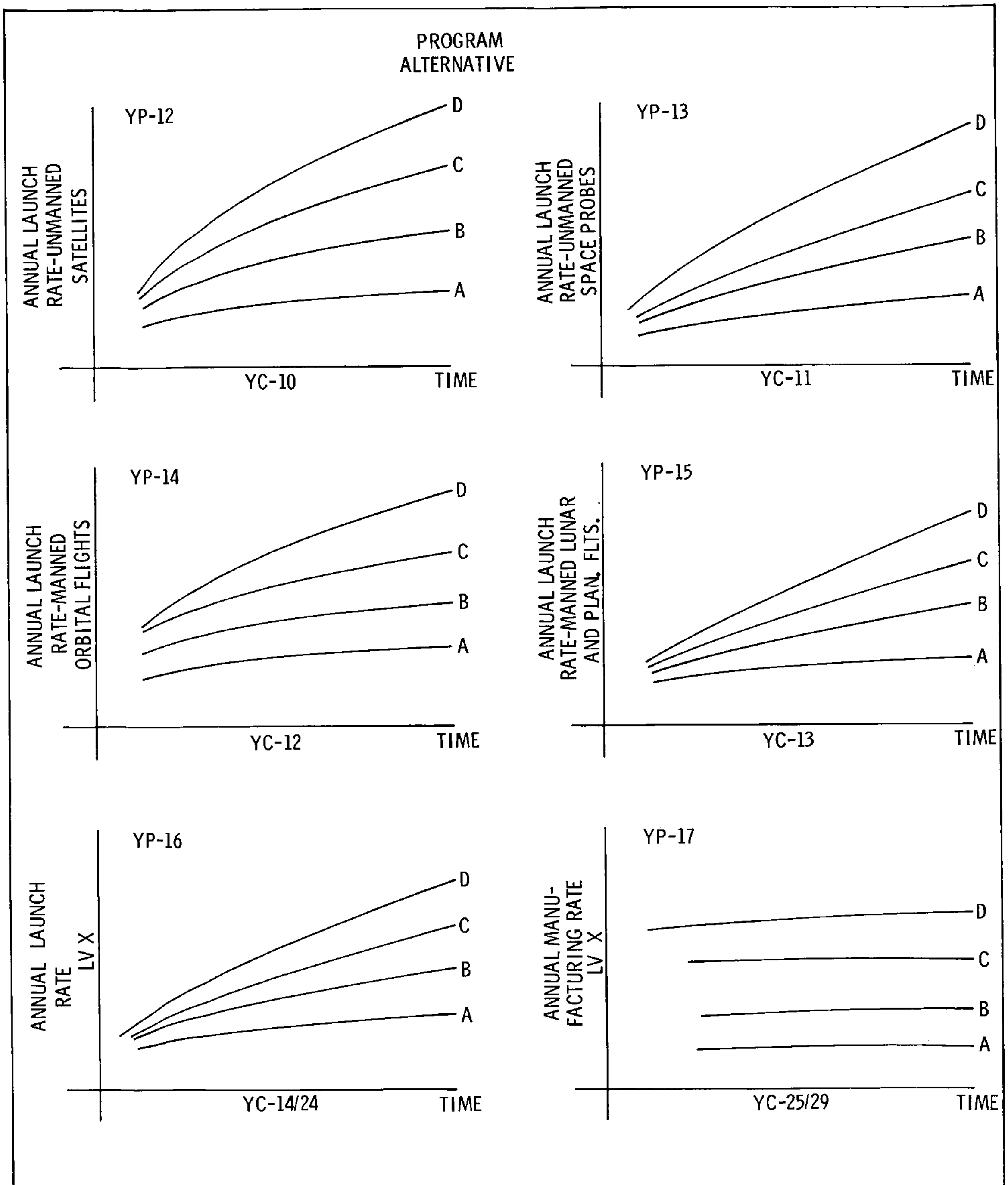

FIGURE VIII-4. YIELD OUTPUT LEVEL 3 (Cont'd)

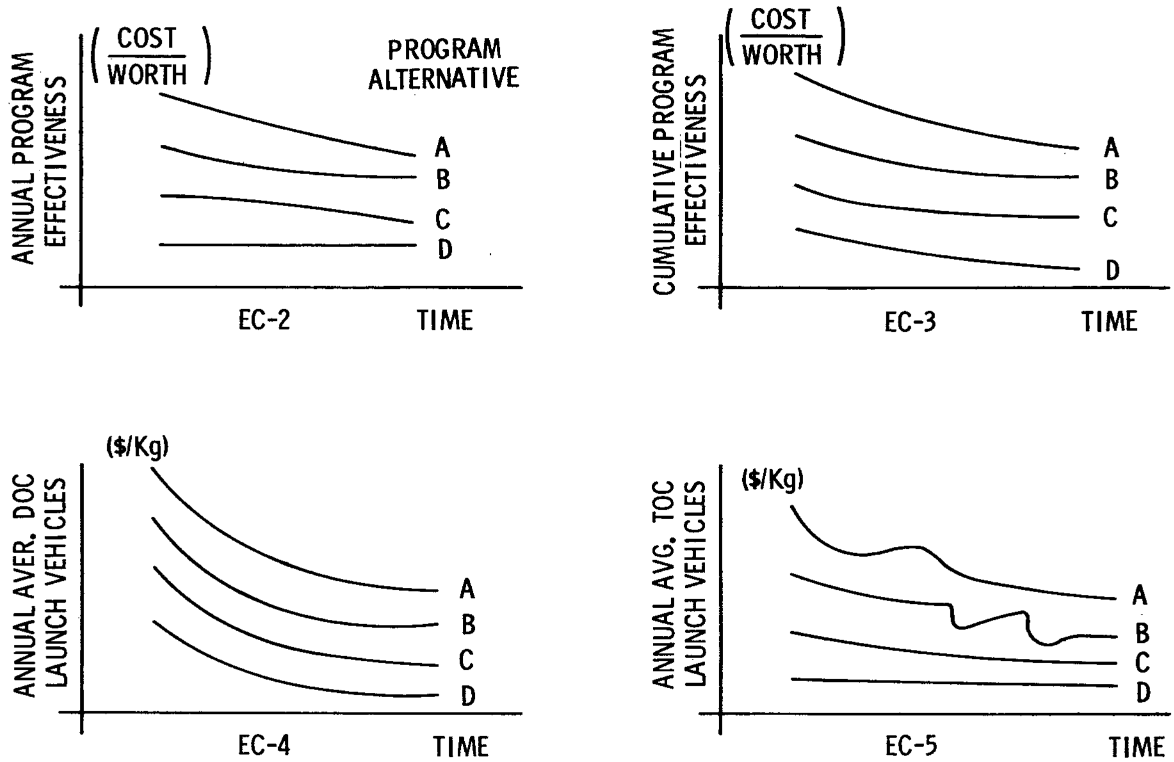

FIGURE VIII-5. PROGRAM EFFECTIVENESS OUTPUT LEVEL 3

March 3, 1965 APPROVAL TM X-53212

A PROCEDURE TO ANALYZE AND EVALUATE ALTERNATIVE SPACE PROGRAM PLANS

By

H. H. Koelle and R. G. Voss, Editors

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